[Proc. Roy. Soc. Victoria, **49** (N.S.), Pt. I., 1936.]

Art IX.—*Soil and Pasture Studies in the Mount Gellibrand Area, Western District of Victoria.*

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[Read 9th July, 1936; issued separately, 23rd November, 1936.]

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I. Introduction.

The large area of land derived from basaltic material in the south-western part of Victoria is interesting from several points of view. Part of it produces high-grade wool; in other sections there are extensive dairying settlements; and near the volcanic cones, which are scattered about the district, there are fertile soils which are largely used for producing crops such as onions and potatoes. Even casual observations show that the number of soil types is quite considerable, although the basalt itself is petrologically uniform over wide areas. A detailed study of a single area in this district has been undertaken in order to obtain useful information concerning a group of soils about which little has as yet been published, and also to explain some of the reasons for the differences between these types. Since this volcanic country includes various kinds of pasture, and numerous attempts at improvement of pastures have been made with varying success, the relation between soil types and pasture has also been studied.

It was decided to choose for this survey some point that would be typical of the volcanic country, and in which the geology would not be complicated by non-basaltic material. Mr. R. A. Ramsay of "Mooleric" and Mr. Urquhart Ramsay of "Turkeith" were kind enough to agree to co-operate in this work. These two stations comprise about 12,000 acres, and are fairly close to the Prince's Highway at a point about half way between Winchelsea and Colac. Mount Gellibrand near the centre of this region provided one volcanic cone in the area surveyed.

Surveyed maps of the stations, on a scale of 1 to 6,336 were made available through the courtesy of the owners, and these were used for the first stages of the survey. However, after the main soil types had been recognized, it was clear that it would be very laborious to try to map the area on the ground, owing to the extent to which the various types are interwoven. The Royal Australian Air Force were therefore approached, and asked if they could make the area the subject of a photographic survey. They very courteously agreed to help, and the photographs were taken on 30th September, 1932, when the water from the winter rains was still lying on the least drained swamps, and the spring growth had begun on the drier land. Three photographic mosaics, on a scale of 1 to 6,840 were prepared, and these were used in the field for the next visit. These aerial photographs were invaluable, and, as will be shown in more detail below, it was possible after a few days' experience to identify each type of soil and map it directly from the photograph. These sketches were then checked by visiting each paddock, and identifying in the field the soils deduced from the photograph; the final map is reproduced in this paper.

II. Topography.

The area studied forms part of the general plain of the Western District. The central feature is Mount Gellibrand (872 feet), a volcanic cone with a flat top about half a mile in diameter, its sides having a slope of approximately 20 deg. The regularity of the cone is broken by occasional outcrops of basaltic rock, and also, on the south-eastern side, by a small subsidiary cone—" Little Mount ". On the western side, a flow of basalt extends from the cone for half a mile over the plain. The steep sides of the cone pass by a sudden transition to gentler gradients which extend outwards for about a mile to the south-east, and half a mile to the north, west, and south.

On the eastern boundary of the area lies Mount Pleasant (500 feet), a much smaller volcanic cone of gentle slope, rising only about 100 feet above the general level of the plain. A flow of basalt from this cone has covered the north-eastern corner of Mooleric station, so that this section lies about 50 feet above the rest of the plain.

Elsewhere, the plain averages about 400 feet above sea level, and falls away very gradually from the mount in all directions. The plain is marked by numerous " stony rises ", which are a striking feature of the country (see Plate VI., Fig. 3). These rises are rocky mounds ranging in height up to about 20 feet, and varying in steepness, shape and extent. Their distribution is for the most part irregular, but some give the impression of being connected into chains. The most conspicuous of these chains occurs in the south-eastern part of the area, where a high wall with occasional breaches extends for about two miles. The rises show great variation from this extreme case down to low outcrops of basalt which, though scarcely worthy of the name of rises, have a considerable effect on the soil. Those rises which have a large area are often broad and flat and comparatively free from rocks; swamps are often developed on such rises. Small swamps are also common at the foot of the steeper rises at the point where the gradient changes abruptly.

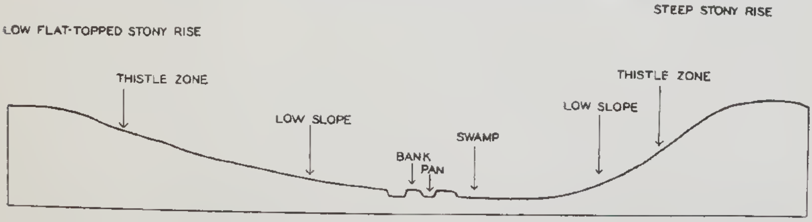

Fig. 1. Section from Stony Rise through Swamp to Stony Rise.

Surrounding each stony rise and varying with it in size and shape is an area of gently sloping ground free from basalt boulders. This changes gradually to flatter ground with typical swamp formations, which will be described later. These transitions are illustrated in Fig. 1. Apart from the mount, the entire country studied may be regarded as a repetition of the sequence stony rise—rock-free slope—swamp—slope—stony rise.

The central position of the Mount, and the fact that there is a gentle slope away from it in all directions, together offer the key to the drainage of the area. The south-west section drains away to Lake Thurrumbong, a somewhat saline, impermanent sheet of water. The south-east section, in which the gradient is rather greater, drains to the Barwon River. The north-east section drains directly to Lake Murdeduke, which is highly saline. The north-west section drains to Lake Calvert, which, in very wet seasons, overflows into Lake Murdeduke. There are no natural water-courses in the area, drainage consisting merely of the movement of water from one swamp to another during the period of heaviest rain. This is probably due to the very gentle fall in general level of the plains, combined with the interruption of the main drainage flow by the irregularly placed stony rises.

III. Geology.

A. History of the Area.

In late Tertiary times this part of Western Victoria was apparently low-lying country which was affected by the extrusion of basaltic lava. The Geological Survey records this lava as " Newer Basalt ", and from the evidence in different parts of Western Victoria, this period of volcanic activity is said to have been in the late Tertiary and lasted until the end of the Pleistocene period. There is, therefore, the possibility of a difference in age of flows belonging to the " Newer Basalt " of the order of a million years, and such a difference must be important in the comparison of soils from different Newer Basaltic areas.

In the Mount Gellibrand area, the evidence of numerous bores indicates a basalt layer varying in thickness from 20 to 200 feet. Friable bands, which are almost invariably encountered during boring, suggest that there have been several flows of basalt, separated by layers of tuffaceous material, or by soil formed on the surface of one flow before the extrusion of the next. The gradual fall in general level away from the mount suggests that it was a centre of effusive activity, although the Newer Basalts are sometimes thought to be of the fissure-eruption type.

The small flow of basalt from Mount Pleasant across the north-eastern part of Mooleric station probably occurred after the extrusion of the main basalt sheets, since it appears to overlie them. The volcanic activity then became more violent, and the central cone of Mount Gellibrand was formed. This cone consists of bedded tuff and scoriaceous material, and its centre is filled by a plug of compact basalt. There are evidences of minor explosive vents, while numerous outcrops of very dense basalt are the result of dykes formed in the crater wall. The basalt flow mentioned as occurring on the west side of the cone ("Rocky Mount") probably represents a flow from one of these dykes.

As already noted, the lower slopes of the mount extend further towards the south-east than in any other direction. This is presumably due to the direction and intensity of the winds prevailing during the period of violent eruption. At the present time, the prevailing winds during winter and spring come from the north and north-west. Since the main physiographic features of the continent had already taken their present shape at the time of the eruption, one may assume that the prevailing winds of those days came from the same quarter as at present.

Apart from the mount, there is no evidence of bedded tuff over the area, but a large amount of fine material must have accompanied the coarser fragments and accumulated to a considerable depth over the basalt sheets of the plain. Evidence for this is found in the presence of a large proportion of quartz grains in most of the soils of the plains. Much of this quartz belongs to the coarse sand fraction of the soil, and is therefore too large to have been brought in from other districts by the wind.

The stony rises are characterized by columnar jointing on a large scale, with the joints at right angles to the exterior slope of the rise. This feature proves that the original cooling surface of the lava had the same topography as the present surface, and that the rises are original features of the basalt and not merely residual mounds left during the process of erosion. The surface of the blocks is bare, but soil fills the cracks. The proportion of soil to rock decreases as the rises become steeper. The origin of these stony rises is somewhat doubtful, and from the standpoint of soil formation is important only in connection with their age in relation to the ash. As will be seen from the description of the soil minerals, the deposits of ash from Mount Gellibrand appear to have covered the rises, which must therefore be older than the explosive phase. The absence of bedded tuff or ash over the plains makes it probable that the explosive material was deposited over the cooled surface of the basalt, and so suffered no hardening and was not preserved as consolidated rock.

The ash has now been almost completely removed from the summits of the rises, and it is probable that most of it was washed away either by volcanic rains accompanying the eruption, or by later rain acting on the fine unconsolidated material. Any soil forming on the surface of the rises is at present removed in a similar manner.

B. Petrology.

Volcanic Scoria and Tuff.

The materials formed during the explosive phase of eruption show great variation. On the mount, reddish-brown vesicular lava occurs, but is not as common as bedded grey tuff with well-marked bands of fine and coarse fragments. In one restricted locality on the north-east slopes of the mount, numerous rounded pebbles up to 2 inches long occur in the tuff. Most of these are of reef quartz, but a few consist of sedimentary rock with fine quartz veins. These pebbles appear to be water-worn, and probably represent pre-basaltic river gravels thrown out by the volcano during a minor eruption.

These fragmental rocks are incoherent, and accordingly difficult to section, but the sections obtained serve to show that they are typical basalt tuffs. Much of the rock consists of brown, highly vesicular glass in which well-formed olivine phenocrysts up to 2 mm. in diameter are common, sometimes with a narrow border of iddingsite. Lath-shaped crystals of plagioclase occur in all the sections, their size depending on the degree of crystallization of the lava fragments. Augite and iron oxide occur rarely, and only in the more crystalline material.

A varying amount of non-basaltic material, mainly quartz, is included in the tuff. The grains of quartz are usually rounded, and often contain lines of bubbles such as are common in reef quartz. They show no noticeable reaction rim, and probably represent pre-basaltic material such as marine Tertiary sands ejected by the volcano during its explosion. Other common detrital minerals such as zircon, tourmaline, and kyanite have also been observed in the tuff.

The amount of non-basaltic material in the tuff was determined by disintegrating the rock (by soaking with water and freezing) and counting the number of quartz grains in a definite sample of material of diameter between 0.2 and 0.02 mm. The grey banded tuff showed about 20 per cent. quartz, and the red scoria, which appeared to be the least contaminated of the fragmental rocks, showed 10 per cent. quartz. It seems likely that the finer ash which fell over the plains would be still richer in quartz grains, the larger and heavier fragments of basaltic lava being concentrated near the mount. The basaltic minerals in the fine ash would decompose very rapidly, leaving only the quartz.

Basalt of the Plains.

This is a grey, coarse-grained, vesicular olivine basalt. Microscopically it shows phenocrysts of olivine with a reaction rim of iddingsite varying in width, the whole crystal sometimes showing the iddingsite colouring. The ground mass consists of an ophitic intergrowth of augite and plagioclase felspar, with grains of iron oxide, either magnetite or ilmenite. The augite has the "titanium violet" tinge, suggesting that some at least of the iron oxide is ilmenite. The refractive index of the plagioclase is between 1.555 and 1.575, and very close to the latter, indicating a composition approximating to labradorite.

A varying amount of interstitial brown devitrified glass occurs, with a lattice-like growth of needles of iron oxide. This glass is particularly abundant around the numerous vesicles. These vesicles are often lined with hyalite.

Included fragments of reef quartz, up to 2 inches in diameter, have been observed in specimens from several localities, and these show a marked reaction rim.

Rosiwal measurements on five samples from different parts of the area gave the following average result: Plagioclase 37.0 per cent., Augite 22.5 per cent., Olivine 10.3 per cent., Iron oxide and glass 29.8 per cent.

Basalt Dykes of the Mount.

This basalt differs from the basalt of the plains in being extremely fine-grained and compact. Olivine phenocrysts (with the iddingsite alteration) and a few large augite crystals occur in a fine ground mass of the usual basaltic minerals. Included rounded quartz grains occur in these dykes, and show marked reaction rims. The plug which fills the centre of the cone is of the same nature.

IV. Description of Soil Types.

The various types recognised in this survey are referred to here as Types 1, 2, etc. The individual samples have been numbered according to a decimal system by which the first digit or the first two digits correspond to a soil type—thus 401, 402, etc., all belong to type 1 (see below).

A. Soils of the Plain.

The most striking features of the plain are the stony rises from which the land slopes down to swampy depressions. The soil types show well-marked changes as one passes from stony rise to swamp. Milne (1935, i., ii.) has suggested the word "catena" to cover a sequence of soils in cases where characteristic types have developed on hilltops, slopes, and basins; he quotes as an example a catena in Uganda including shallow greyish-black soil on the hilltops, deep red soil on the slopes, grey sandy soil on the fringe of the swamps, and intensely black acid clay on the swamps. The sequence here described from stony rise to swamp appears to be an excellent example of such a catena. While this variability is to be expected in a region of stony rises and irregular drainage, it is not characteristic of the whole of the volcanic plains of Western Victoria.

(*a*) *Soils with Surface Drainage.*

On the rises themselves, the rock is always close to the surface, and the soils fall into two classes, separated according to their depth.

Type 1.—STONY RISE BROWN LOAM. (Sample numbers beginning 40 . . .)

On many of the steeper rises, the soil is only three to six inches deep, and the rocks are in a fresh state and very close together. This soil is a friable brown to dark brown loam, often dusty; it is rich in organic matter, and of good fertility. From its shallowness and absence of horizons, and the presence in its sand fraction of large amounts of unweathered basaltic minerals, it appears that this brown loam is highly immature.

Type 2.—STONY RISE CLAY. (Sample numbers beginning 47 . . .)

Some rises have broad flat tops, and the outcropping rocks are then relatively far apart. The soil on these rises is a dark grey to dark brownish-grey clay loam or clay, about a foot deep. This type is used to include transitional forms between type 1 and types 4 and 5, but it is always more fertile than the latter types.

Type 3.—THISTLE-ZONE SOILS. (Sample numbers beginning 3 . . .)

A very conspicuous vegetational feature of the country is the band of thistles (*Carduus pycnocephalus*) surrounding each stony rise, and extending for twenty yards or more in every direction from the main outcrop. These thistles are associated with a soil type, of which the following profile is typical, although rock is often struck in this zone before the third foot has been bored:—

Horizon 1 (0 to 6 inches).—Dark grey or dark brownish grey clay loam or clay, somewhat friable, breaks up on drying into small cubes; sticky when wet. pH between 6 and 7.

Horizon 2 (6 to 25 inches).—Dark grey to black heavy clay, with a yellowish tinge appearing at about 20 inches. pH about 7 increasing with depth.

Horizon 3 (25 to 36 inches).—Greyish yellow calcareous clay, with maximum $CaCO_3$ at about 36 inches, both as soft lime and as concretions up to an inch in diameter. This clay is plastic and only the more highly calcareous bands are at all friable. pH 8.0 to 8.5.

Horizon 4 (below 36 inches).—Calcareous clay mottled yellow and grey, lying over basalt.

This soil forms deep cracks in dry weather, and is often marked by puffs of darker soil, more friable and more intensely cracked than elsewhere. These puffs are analogous to those found in the "crabhole" areas (described later), though they are less well developed here than in the true crabhole areas, and are only occasionally calcareous on the surface. The association of thistles with this type of soil may be due either directly or indirectly to its relatively high lime status, or to the self-mulching tendency of the soil; thistles are in fact found especially on the puffs, which have these properties best marked. The thistle zone is also more fertile than the lower slopes, no doubt because the soil has been constantly enriched by the addition of the finer particles formed from the weathering of the basalt and washed off the stony rise.

The result of the addition of clay by this process is that the thistle-zone soils are high in clay even though the neighbouring soils on the rises and on the slopes may be sandy. Thus, the lightest sample taken of this type contained only 40 per cent. of total sand in the top 6 inches, compared with 49 per cent. in the top 9 inches of the soil on the corresponding rise 7 yards away, and 69 per cent. in the top 9 inches of the soil on the slopes 25 yards lower down (Type 4). Besides the addition of clay it is likely that the thistle zones are unique in receiving water by seepage as well as by run-off, and this may be responsible for their relatively high base status.

Type 4.—Low Slopes (lighter type). (Sample numbers beginning 0 . . .)

This and the next type are the normal soils of the area. They are found wherever the land has a gentle slope and is neither rocky nor swampy. The profile of this lighter type may be generalized as follows:—

Horizon 1 (0 to 8 inches).—Non-coherent grey or light grey sandy loam, often lighter in colour below 2 inches. pH about 5.5. Change to heavier underlying soil often sharp.

Horizon 2 (8 to 14 inches).—Grey sandy clay; this is transitional between the surface and the next horizon, and may occupy less than 6 inches. pH about 6.5.

Horizon 3 (14 to 30 inches).—Grey heavy plastic clay, drying to columnar structure. pH rises from 7 to 7.5 in the upper layers to about 8 at the 24-inch level, at which a yellowish colour appears.

Horizon 4 (30 to 70 inches, or until rock is reached).—Greyish-yellow calcareous clay, with a maximum of $CaCO_3$ in both soft and nodular forms at 36 inches. pH value 8.3 to 8.7; below 36 inches yellow-grey mottling is common. An exposed profile of this soil in a trench shows the greyish-yellow clay interspersed with brown and black streaks along cracks occupied by old roots. Roots were seen throughout this horizon. This clay is plastic except where lime content is fairly high. Bedrock is usually reached at a depth of between 5 and 8 feet.

The depth of the lighter soil of the surface is variable, being usually from 5 to 9 inches where this type is best developed but rising to 12 to 18 inches on the lower and gentler slopes of Mount Gellibrand itself. Buckshot nodules of iron oxide, up to 5 mm. diameter, are often seen on the surface of these soils, and are in fact fairly generally distributed over the plains and swamps to the extent of 1 or 2 per cent. through all horizons, including calcareous subsoils. This soil type is characteristic of the gentler slopes to the west, south, and east of Mount Gellibrand, and extends uniformly over considerable areas where Mounts Gellibrand and Pleasant merge into the plains. On the northern side of the cone, however, at a little over 2 miles from the summit, the normal soil of the slopes is a heavier type, and is described here as Type 5.

Type 5.—Low Slopes (heavier type). (Sample numbers beginning 00 . . .)

The profile of this type differs from that just described in having less sand. The surface soil is a dark grey clay loam or light clay which dries to form intractable clods; below 8 inches it passes to a grey heavy clay, and the subsoil is very similar to, though less sandy than, that of Type 4. The pH of the surface soil, however, is rather higher than that of Type 4 (about 6.0). This soil has been relatively little affected by the sand thrown up by the volcano, and appears to be typical of the heavy, infertile grey clays that are common in this part of the Western District. The figure of 50 per cent. sand was arbitrarily taken to separate the light soils (Type 4) from the heavy soils (Type 5) for mapping, though there is a steady transition from one type to the other. This value may be justified by two facts:—(*a*) that the degree of cracking of the soil becomes marked when there is less than 50 per cent. of sand, (*b*) that this line also marks off the "crabholey" areas (which, in Turkeith, lie entirely to the north of it).

(*b*) *Swamp Soils.*

Large areas of soil have been developed under conditions of periodical waterlogging. These soils may be classified as two "complexes," here called "pan and bank" and "crabhole."

Pan and Bank complex (Sample numbers beginning 1 . . .).

These areas consist of pans of grey clay (Type 6, below) separated by narrow banks in which the surface soil is of similar texture to the adjacent low slope. The axes of the pans may vary from 1 to 50 yards in length, while the banks are a yard or two across and rise about a foot above the level of the pans. Every intermediate stage is represented from normal low slope to normal pan and bank; there are areas where the banks are wide in proportion to the pans, and such half-developed forms of the complex are mapped separately. They are more poorly drained than the normal slopes, and tussocks of *Poa caespitosa* are common in the hollows. At the other extreme there are low-lying swamps which consist entirely of the grey clay pan, without any bank.

Type 6.—Grey Clay of Swamps.

Horizon 1 (0 to 6 inches).—Steely grey clay, with rusty streaks; drying to hard clods.

Horizons 2, etc.—Grey heavy clay, as with Types 4 and 5, passing to calcareous clay at about 30 inches.

Since the soils of the slopes in the north of the area (Type 5) are as clayey as the swamps, there is little or no contrast in texture between pans and banks in this sector, though there is a marked contrast in their flora. On the south of the mountain, however, the sandy banks are loams or sandy loams while the pans are light or medium clays. When a trench is dug through this complex it is seen that the bank is a layer of the lighter soil resting on a subsurface of clayey soil like that of the pan (see Fig. 2). Table I. shows that the texture of the bank resembles that of the neighbouring low-slope. The aerial photographs (Plate V., upper photograph) reveal that the pans are elliptical, with their longer axes at right angles to the line of flow of water during the winter. Owing to the impervious nature of the subsoil, this swampy complex occurs not only on the actual basins but also on patches of level, higher ground.

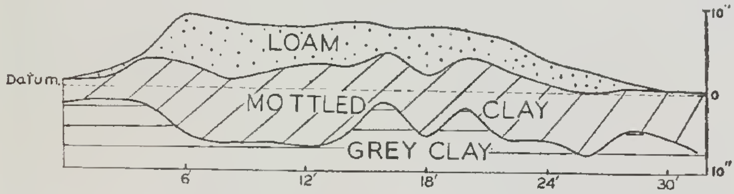

Fig. 2. Section through Pan-and-Bank Complex.

This formation is presumably due to the sorting action of water. Since cultivation destroys the complex it is not surprising that it has not been described elsewhere.

Table I.—Sandiness of Soil of Banks and Corresponding Pans, compared with Neighbouring Low Slopes.

Pan and Bank Sample.	Bank.		Pan.		Nearest low slope	
	Depth inches.	Total Sand.	Depth inches.	Total Sand.	Depth inches.	Total Sand.
		%		%		%
160–1	0–3 3–10	70 46	0–8 8–20	46 41	0–8 ..	64 ..
170–1	0–10 10–18	62 39	0–12 12–24	29 26	0–6 ..	59 ..

Although the soils on the slopes are here described as differing from the non-calcareous swamp soils, the profiles of all three types 4, 5, and 6 are similar in many features such as the presence of "buckshot" (iron oxide concretions) and the level of the calcareous layer; the flora of a swamp that has been drained is similar to that of the slopes around it. The absence of a well-marked difference between the profiles of soils of these types is probably due to the fact that drainage has been poor even on the slopes because of the impermeability of the subsoil—i.e., the slopes have only " surface " drainage, or run-off. The presence of buckshot throughout these profiles also seems to reflect their liability to periodical waterlogging. Any genetic account of the soils of the plains would have to treat the low-slope types and the pan-and-bank swamps as one group as contrasted with the stony-rise and crabhole types.

Crabhole Complex (Sample numbers beginning 2 . . .).

The " crabhole " type of formation is found in certain swampy patches, almost all of which lie on the northern margin of the surveyed area, three miles or more from the top of Mount Gellibrand. These areas consist of alternate puffs and depressions, the pattern of which is well shown in the lower photograph of Plate V. The surface soil of the puffs has a " self-mulching " tendency; that is, it crumbles in dry weather into loose structural units, which are cubical with a side of about 1 centimetre. At the same time, deep and wide cracks are formed. The soil is calcareous; when it is dry and ground up its colour is grey to dark grey; but in the field it often looks black especially along the cracks. The puffs are roughly circular, normally about 3 feet across, and the centre of each may be 6 or 12 inches higher than the margin. In patches of well-marked crabholes, each puff is separated from its neighbour by a flat depression, 3 to 6 feet across. The soil of the depressions contains more sand than that of the puffs. It is grey to dark grey, and it also cracks in dry weather, but is not calcareous and has no self-mulching tendency but dries into hard clods. The far greater volume occupied per unit mass by the soil of the puffs, as compared with the soil of the depressions is easily shown by means of the post-hole auger; it is necessary to remove about twice the weight of soil from the depression as from the puff in order to reach a depth of 1 foot. The following profiles may be taken as typical:—

Type 7.—Crabhole Puff—

Horizon 1 (0-6 inches).—Grey clay, containing calcium carbonate in both soft and concretionary form. Sticky when wet, drying to cubical granular structure.

Horizon 2 (6-36 inches).—No definite transition between this and horizon 1, but structure becomes less definite from the surface downward. Yellower tendency at bottom.

Horizon 3 (36-bedrock).—Greyish, yellow calcareous clay, with sharp transition from horizon 2. This is identical with horizon 4 of Type 4.

Type 8.—Crabhole Depression—

Horizon 1 (0-4 inches).—Grey to dark grey clay, non-calcareous and of cloddy structure.

Horizon 2 (4-27 inches).—Grey to dark grey heavy clay, with yellowing tendency at bottom.

Horizon 3 (27-bedrock).—Identical with horizon 3 above, and continuous with it, as shown in Fig. 6.

In a series of surface samples (0 to 3 inches) which were taken at 8-inch intervals from the centre of a typical puff to the corresponding depression, the pH value was found to change steadily from 7.9 at the centre to 6.9 2 feet away down to 5.8 4 feet away. Below 30 inches, however, the subsoils are identical with each other and with the deep subsoils of the other types—viz., greyish-yellow, somewhat calcareous clay with occasional bands of more calcareous nature with limestone concretions, extending down to the parent rock.

It may be suggested that, in view of the fact that the various types 1, 2, and 3 are essentially derived from basalt, and that types 5, 7, and 8, though affected in this area by tuff, are very similar to soils in analogous situations lying on basalt and unaffected by tuff, it is desirable that the unqualified term "basalt soil" should disappear from scientific literature.

B. Soils of the Mountain.

The lower and gentler slopes of Mount Gellibrand, and most of the slopes of Mount Pleasant, carry the low-slope type of soil in which the loamy character of the surface soil extends to about 12 inches. Halfway up Mount Gellibrand, however, the slope becomes steeper and the soil changes within a few yards to a dark chocolate type of high fertility, as follows:—

Type 9.—Mountain Soil (Sample numbers beginning 41 . . . and 5 . . .)—

Horizon 1 (0-8 inches).—Dark chocolate clay loam to clay, rich in organic matter and quite friable.

Horizon 2 (8-16 inches).—Dark brown friable clay with fragments of tuff.

Horizon 3 (16-25 inches).—Brown or pinkish calcareous clay, with considerable tuff.

Though horizons have developed in this soil, the presence of tuff close to the surface, and of active minerals like augite in the fine sand fraction of the surface itself, shows that the type is much less mature than the normal soil of the plain or of the lower part of the mountain. This relative immaturity is probably due to continual erosion; the erosion in this case is of the whole surface soil—including sand—as contrasted with the washing away of fine fractions only from the stony rises. Calcium carbonate is sometimes very copious in the subsoils of this type, reaching over 40 per cent. in one case. This may contribute to the relatively good permeability of the subsoil. Patches of soil occur with a surface of heavy clay texture and pH over 7; such cases are obviously due to excessive erosion.

V. Chemical and Physical Analyses of the Soils.

A. Mechanical Analyses.

Complete mechanical analyses were carried out on selected profiles from each type of soil. The details are given in Tables III. to IX., in which the percentages are in terms of oven-dry soil. The figures have also been recalculated to a basis of sand + silt + clay = 100, and the results of individual samples are plotted in triangular form in Figs. 4 and 5, while mean figures for each type are collected in Table II., and plotted as a summation curve in Fig. 3. It will be seen that the texture of the subsoil is a medium or heavy clay in most cases; the separation of types from one another must rely on differences between surface soils.

Type 4 has the lightest texture; although this includes any low-slope soil of more than 50 per cent. sand, the normal soil in the region covered by this type has at least 60 per cent. of sand, and the texture is loam or sandy loam. The stony-rise loams are next in increasing order of clay; although some of these contain enough clay to fall into the class of clay loams, the high content of organic matter causes them to have a loamy feel. The surface soil of the bank in the complex named "pan and bank" has a texture similar to that of the neighbouring slopes.

The soils of the mountain vary over a considerable range of texture; here again the organic matter contributes to increase the friability. These soils also include those that are highest in silt.

Of the remaining types, one may note that the crabhole puffs are higher in clay than any other type—this is not surprising if it is correct to regard the puff as an old subsoil. The other surface soils are mostly clays of varying heaviness.

It is interesting to note that, if the mountain soils are excluded, all the soils plotted here (with two unimportant exceptions) lie in the band of 10 to 20 per cent. of silt.

The texture of the subsoils (Fig. 5) calls for little comment. The greater sand content in the subsoils of Type 4 is apparently not enough to improve their permeability over that of the other subsoils. The subsoil of profile 006 (Type 5) is exceptionally sandy; other subsoils of this type, although not completely analysed, have much less sand than this.

The amounts of gravel in the various types are in most cases not recorded. The surface soils of the stony rises are always stony, as are those of the mountain which are derived from basalt. Among the maturer types on the plain, buckshot gravel is general from surface to deep subsoil, but it amounts only to about 2 per cent. of the field sample. The other source of material coarser than 2 mm. is an occasional concretion of calcium carbonate in the subsoil at or below a depth of 3 feet.

TABLE II.—AVERAGE COMPOSITION OF SOIL TYPES IN TERMS OF SAND + SILT + CLAY = 100.

Soil Type.	Coarse Sand.	Fine Sand.	Silt.	Clay.
1	18	40	16	26
2	16	29	16	39
3	10	22	16	52
4	27	41	17	15
5	18	20	11	51
6	8	22	17	53
7	6	18	15	61
8	11	27	17	45
9	10	30	20	40

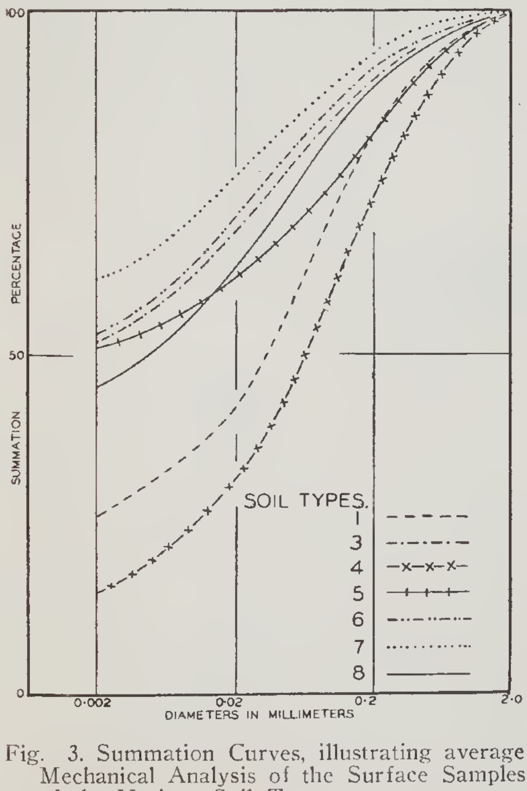

Fig. 3. Summation Curves, illustrating average Mechanical Analysis of the Surface Samples of the Various Soil Types.

Fig. 4. Distribution of Mechanical Compositions of Samples of Surface Soil of Various Types. The sign of a cross inside a circle represents a bank of pan-and-bank complex.

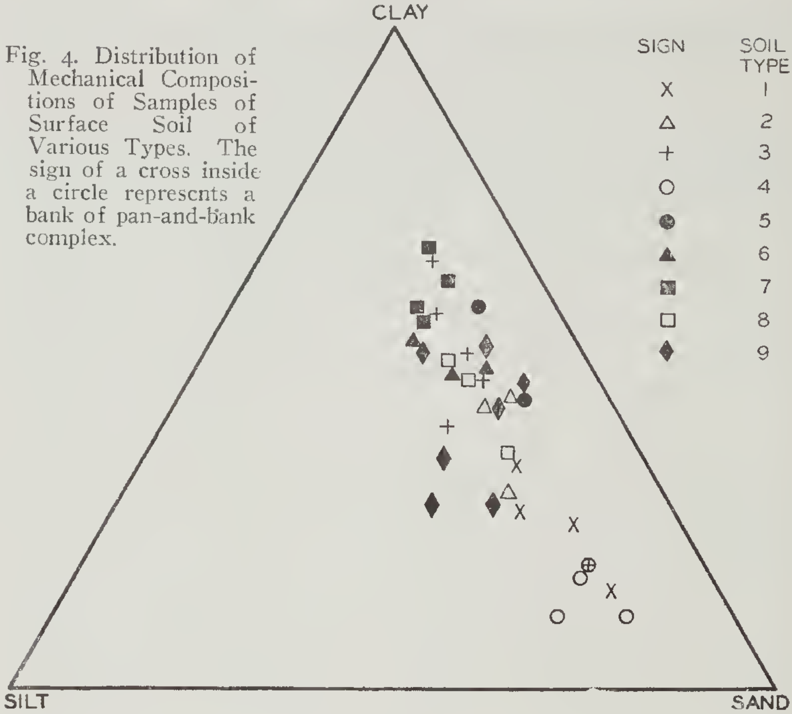

Fig. 5. Distribution of Mechanical Compositions of Samples of Subsoils of Various Types.

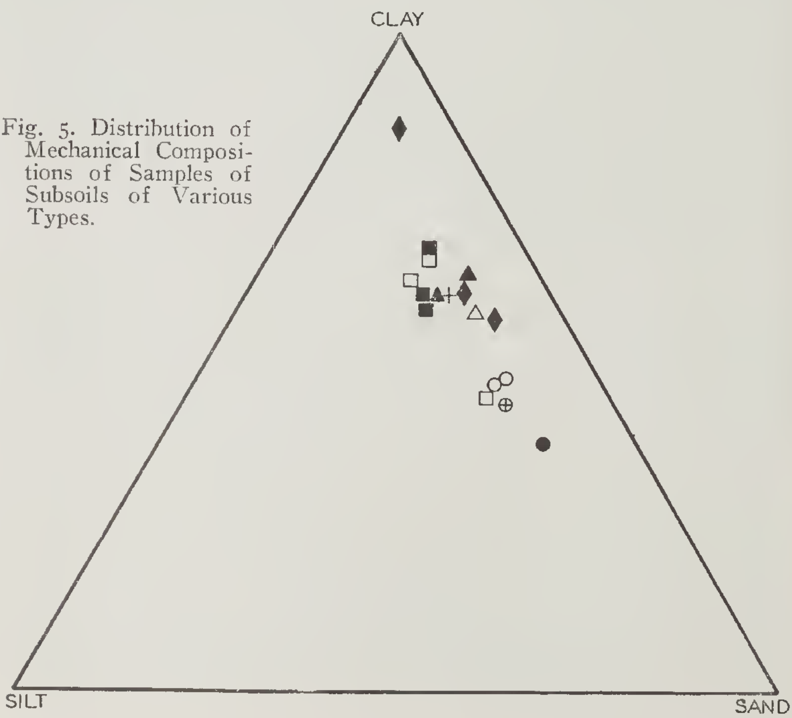

TABLE III.—MECHANICAL ANALYSES OF SOILS OF TYPES 1 (STONY RISE BROWN LOAM) AND 2 (STONY RISE CLAY).

Soil No. ..	4001	401	4011	404	471	472	475	..
Type	1	1	1	1	2	2	2	..
*Horizon ..	a	a	a	a	a	a	a	b
Depth (inches) ..	0–9	0–8	0–5	0–6	0–5	0–3	0–6	12–18
Coarse sand ..	11·7	12·1	26·8	15·8	17·3	15·9	10·9	7·0
Fine sand ..	36·8	32·4	36·6	41·2	23·3	22·1	35·2	22·2
Silt	18·3	15·1	12·2	13·2	10·7	15·5	18·9	10·5
Clay	24·8	30·5	13·7	23·7	41·0	40·2	27·5	55·6
Carbon ..	3·31	4·68	4·35	..	2·86	..	3·28	..
Nitrogen ..	·38	·52	·48	..	·252	..	..	..
$CaCO_3$	..	..	..	..	..	..	..	..
pH	5·4	5·8	5·3	5·6	5·7	6·0	5·7	6·4

* The letters a, b, ... g used in these tables refer simply to the order of sampling of the various horizons, a being the first and g the seventh horizon taken in a profile. The letters are not meant to suggest any parallel with the technical meanings of A, B, and C horizons.

TABLE IV.—MECHANICAL ANALYSES OF SOILS OF TYPE 3 (THISTLE ZONES).

Soil No.	302	305	..	..	307	31	311
Horizon	a	a	b	c	a	a	a
Depth (inches)	0–6	0–8	8–22	22–30	0–8	0–9	0–6
Coarse sand	6·5	8·2	8·4	8·5	3·8	16·8	13·2
Fine sand	29·3	16·7	15·9	16·8	16·1	18·5	18·6
Silt	13·6	15·0	12·3	11·9	11·1	21·7	13·7
Clay	44·2	53·7	57·5	58·2	59·4	38·4	47·8
Carbon	..	1·98	..	..	2·26	..	..
Nitrogen	..	·130	..	..	·215	·211	·189
$CaCO_3$	..	..	..	..	2·5	..	..
pH	6·0	6·4	6·6	6·7	8·0	7·0	6·5

TABLE V.—MECHANICAL ANALYSES OF SOILS OF TYPE 4 (LOW SLOPES, LIGHTER TYPE).

Soil No.	01	..	..	0120	014	..	..	..	..
Horizon	a	e	f	a	a	b	c	d	e
Depth (inches)	0–4	12–16	16–20	0–9	0–7	7–16	16–30	30–42	60–72
Coarse sand	21·9	22·9	13·6	33·3	22·7	12·6	16·9	17·9	7·7
Fine sand	40·7	26·4	24·8	38·0	39·9	29·4	20·5	20·3	18·5
Silt	17·0	10·8	13·1	12·8	20·9	16·1	13·9	12·0	14·7
Clay	17·0	37·6	44·9	10·6	10·4	38·6	45·5	46·0	56·6
Carbon	1·88	..	..	0·85	1·01	1·02	..	..	..
Nitrogen	·154	..	..	..	·084	·098	..	..	..
Calcium carbonate ..	..	..	..	..	..	..	tr.	tr.	1·7
pH	5·8	6·5	7·5	5·6	5·4	6·4	7·6	7·8	8·4

Table VI.—Mechanical Analyses of Soils of Type 5 (Low Slopes, Heavier Type) and of Pan-and-Bank Complex Adjoining Them.

Soil No.	002	006	..	..	12	180	..
Type	Slope	Slope	..	..	Pan	Bank	..
Horizon	a	a	b	c	a	a	b
Depth (inches)	0–6	0–7	7–24	36–42	0–12	0–7	7–14
Coarse sand	5·3	28·5	26·9	15·4	5·0	6·6	5·7
Fine sand	25·7	14·0	14·5	33·5	19·0	22·3	20·1
Silt	9·9	10·3	12·0	11·3	20·3	11·0	8·4
Clay	56·2	41·8	42·8	36·5	51·4	55·9	61·8
Carbon	1·64	1·33	1·04	..	..	1·80	1·43
Nitrogen	·131	·096	·093	..	·138	·176	..
Calcium carbonate ..	..	..	..	0·2	..	..	..
pH	6·1	6·0	7·0	8·0	7·0	6·6	6·5

Table VII.—Mechanical Analyses of Pan-and-Bank Complex in Area Surrounded by Type 4.

Soil No.	170 (Bank)	..	..	..	171 (Pan)	..	..
Horizon	a	b	c	e	a	b	c
Depth (inches)	0–10	10–18	18–36	54–60	0–12	12–24	24–30
Coarse sand	27·3	18·0	17·3	6·8	10·6	10·2	9·1
Fine sand	35·9	21·0	22·4	12·4	20·8	18·7	14·7
Silt	15·2	12·1	13·6	13·2	17·3	17·5	13·8
Clay	17·7	46·0	42·0	59·9	46·7	49·1	60·1
Carbon	1·67	1·39	..	..	..	..	..
Nitrogen	·118	·114	..	..	·117	..	..
Calcium carbonate ..	..	..	..	3·9	..	..	..
pH	5·3	5·5	6·5	8·2	6·8	7·2	7·6

Table VIII.—Mechanical Analyses of Soils of Types 7 and 8 (Crabhole Complex: in all three cases the Type 7 and corresponding Type 8 profile were taken within 3 feet of each other).

Soil No. ..	260	..	..	261	..	..	280	..	281	..
Type ..	7 (Puff)	..	..	8 (Depression)	..	..	7 (Puff)	..	8 (Depression)	..
Horizon ..	a	b	c	a	b	c	a	b	a	b
Depth (inches)	0–4	4–12	12–30	0–4	4–20	20–27	0–8	8–20	0–8	8–20
Coarse sand	7·1	7·2	6·1	9·3	5·8	4·9	7·8	8·2	15·5	13·4
Fine sand	17·2	17·5	14·5	24·7	17·0	14·1	15·3	13·6	29·7	23·4
Silt ..	11·4	13·9	13·0	15·9	16·0	16·4	16·3	14·6	16·6	15·3
Clay ..	59·5	56·5	53·3	44·5	56·9	59·8	51·7	50·3	34·1	43·3
Carbon ..	1·08	0·81	..	1·96	1·34	..	1·01	0·78	1·68	..
Nitrogen ..	·114	·076	..	·164	·115	..	·198	·081	·144	..
$CaCO_3$ ..	0·3	0·8	9·8	..	..	..	4·5	10·7	..	..
Rubble (field sample)	..	..	..	..	..	..	..	..	..	..
pH ..	8·0	8·4	8·7	6·4	7·1	7·6	8·3	8·6	6·4	7·2

TABLE VIII—*continued.*

Soil No. ..	270	..	..	..	..	..	271	..
Type	7 (Puff)	..	..	..	..	..	8 (Depression)	..
Horizon ..	a	b	c	e	f	g	a	b
Depth (inches) ..	0–7	7–26	26–41	54–66	66–90	120	0–8	8–24
Coarse sand ..	3·0	4·5	4·2	4·0	4·6	0·9	5·6	3·6
Fine sand ..	14·1	13·2	12·7	7·2	15·0	9·6	23·9	16·2
Silt	10·8	11·7	10·7	9·2	10·5	11·0	16·7	11·8
Clay	58·0	57·1	59·8	48·6	65·7	74·7	46·3	62.9
Carbon ..	2·19	1·19	0·72	..	..	..	3·11	1·46
Nitrogen ..	·247	·149	..	..	..	..	·278	·110
$CaCO_3$	9·0	10·6	11·3	30·0	0·6	0·8	..	..
Rubble (field sample) ..	..	5	7	11	..	..	..	..
pH	8·1	8·6	8·5	8·6	8·4	8·2	6·9	7·6

TABLE IX.—MECHANICAL ANALYSES OF TYPE 9 (MOUNTAIN SOIL).

Soil No. ..	411	412	417	..	..	419	..	50	53	56	..
Horizon ..	a	a	a	c*	d	a	b	a	a	a	b
Depth (inches) ..	0–8	0–8	0–6	12–20	20–26	0–8	8–15	0–6	0–8	0–5	27–33
Coarse sand	8·6	7·7	7·0	14·9	9·8	5·0	3·2	16·8	6·7	9·8	1·2
Fine sand ..	28·5	17·6	25·1	30·9	19·7	36·1	29·7	28·5	26·4	29·1	2·2
Silt ..	27·0	18·8	21·9	21·3	12·4	9·8	8·2	21·5	11·6	13·8	3·4
Clay ..	24·4	45·6	29·8	24·8	50·0	43·9	54·3	25·6	48·5	40·4	44·2
Carbon ..	..	6·45	8·40	..	..	..	..	..	..	3·75	..
Nitrogen ..	..	·52	·64	..	..	..	..	·262	..	·340	..
$CaCO_3$ ..	..	..	..	..	..	..	..	..	..	..	47·0
pH ..	5·8	6·0	5·8	6·8	7·0	6·5	6·9	5·9	6·1	6·4	8·8

* Tuff band.

B. HYDROCHLORIC ACID EXTRACT.

Representative soils were extracted with boiling hydrochloric acid as in the International method. Analyses of these extracts are collected in Table X., from which the following conclusions may be drawn:—

(*a*) The *calcium* content is correlated with the state of saturation of the clay. In the non-calcareous soils there is little difference between the calcium extracted by hydrochloric acid and that extracted by ammonium acetate (exchangeable calcium).

(*b*) *Potash* is, as usual, highly correlated with clay; the light, leached soils of Type 4 contain only small amounts, and the immature soils of Type 1, on the stony rises, also yield relatively little to the hydrochloric acid, although they contain good reserves of potash in their primary minerals. All the heavier types contain ample potash.

(*c*) *Phosphorus* is low or very low in the mature soils; the basalt of this area, like the other basalts of the Western District, contains normal quantities of P_2O_5—viz., .35 per cent. of the rock; but only the immature soils of Types 1, 2, and 9 are well provided with phosphorus. It is possible that the contrast in fertility between the stony rises and the slopes and swamps has been increased by the fact that grazing animals tend to "camp" on the rises; but the very low figures of the mature soils require further study.

Table X.—Hydrochloric Acid Extracts.

—	Sample Number.	Depth.	CaO.	MgO.	K_2O.	P_2O_5.	Mn.
Type 1 (Stony rise brown loam) ..	4001a	0–9	..	..	·16	·125	..
	401a	0–8	..	..	·31	·106	..
	4011a	0–5	·21	·49	·25	·127	·10
	408a	0–3	·26	·39	·10	·116	..
Type 3 (Thistle zone)	307a	0–8	3·60	1·04	·59	·046	..
	31a	0–9	·65	·59	·50	·035	..
	311a	0–6	..	..	·28	..	..
Type 4 (Lighter low slopes)	014a	0–7	..	..	..	·014	..
	09a	0–8	·05	..	·10	·004	·017
Banks of swamps surrounded by Type 4	11a	0–6	·07	·06	·11	·005	..
	170a	0–10	·08	·08	·12	·011	..
	170b	10–18	·18	·25	..	·017	..
	170d	40–48	..	..	·23	·014	..
Type 6 (Clay pan of swamps) ..	171a	0–12	·30	·52	·37	·015	·041
	13a	0–9	..	..	·38	..	..
	180a	0–7	·19	·56	1·01	·025	..
Type 7 (Crabhole puff)	260a	0–4	..	..	·77	·022	..
	270a	0–7	4·94	·90	·98	·046	..
	270b	7–26	5·76	·85	1·02	·027	..
	270e	54–66	..	..	·69	·016	..
	280a	0–8	..	..	·44	·020	..
Type 8 (Crabhole depression)	23a	0–4	·87	·72	·84	·051	·047
	271a	0–8	·48	54	·72	·030	..
Type 9 (Mountain soil)	417a	0–6	·72	·41	·21	·135	·095
	50a	0–6	..	..	·23	·071	..
	56a	0–5	·28	·45	·53	·048	..

C. Carbon and Nitrogen.

Carbon was estimated by Tiurin's method, which consists of oxidizing a half-gram sample of finely ground soil with standard dichromate in 1 : 1 sulphuric acid and titrating the residual dichromate. The organic carbon was calculated using the figure 1 ml. normal oxidizing agent equals 3.45 mg. carbon. This is the figure proposed by Allison (1935) for a similar method, but comparison of the values obtained for selected soils by dry combustion indicates that these figures are about 5 per cent. too high. Nitrogen was estimated in the usual way.

Individual values are included in the tables of mechanical analyses. The results are collected in Tables XI. and XII.

These show that the immature types 1 and 9 are richer than the others in organic matter, while Type 2 is transitional in this as in other respects between Type 1 and the low slopes. Of the remaining types, though the number of samples is small, it appears that the low slopes (4 and 5) are the poorest, while the crabhole depressions and thistle zones (Types 8 and 3) are richer than the other mature soils.

The mean value of the low-slope types, 0.11 per cent. nitrogen, may be compared with the figure 0.108 per cent. found by Jenny (1930) as the most likely value for nitrogen in a soil under grass in undulating country in a climate of rainfall 22.7 inches, mean temperature 13.5° C., and saturation deficit 0.131 inch (these being the figures for Mooleric station). The carbon-nitrogen ratio generally lies between 9 and 14, with a mean of about 11.

TABLE XI.—DISTRIBUTION OF NITROGEN CONTENT OF SURFACE SOILS.

—	Mean.	·05–·10.	·10–·15.	·15–·20.	·20–·25.	·25–·30.	·30–·35.	·35–·40.	·40–·50.	·50–·60.	·60–·70.
Type 1 (Stony rise brown loam) ..	·44	..	..	..	..	..	..	1	1	1	..
Type 2 (Stony rise clay)	·25	..	..	..	..	1	..	..	..	..	..
Type 3 (Thistle zone)	·19	..	1	1	2	..	..	..	..	..	..
Type 4 (Low slopes, light type) ..	·12	2	2	2	..	..	..	..	..	..	..
Type 5 (Low slopes, heavy type) ..	·11	1	1	..	..	..	..	..	..	..	..
Type 6 (Clay pan of pan and bank complex)	·14	..	3	..	1	..	..	..	..	..	..
Type 7 (Puff in crabhole complex) ..	·16	1	1	2	1	..	..	..	..	..	..
Type 8 (Depression in crabhole complex)	·22	..	1	1	..	2	..	..	..	..	..
Type 9 (Mountain soils)	·44	..	..	..	..	1	1	..	..	1	1

TABLE XII.—DISTRIBUTION OF CARBON CONTENT OF SURFACE SOILS (BY TIURIN'S METHOD).

—	Mean.	1·0.	1·0–1·5.	1·5–2·0.	2·0–2·5.	2·5–3·0.	3·0–4·0.	4·0–5·0.	5·0–6·0.	6·0–8·0.	8·0–10·0.
Type 1 ..	4·1	..	..	..	..	..	1	2	..	..	..
Type 2 ..	3·1	..	..	..	..	1	1	..	..	..	..
Type 3 ..	2·1	..	..	1	1	..	..	..	..	..	..
Type 4 ..	1·2	1	2	1	..	..	..	..	..	..	..
Type 5 ..	1·5	..	1	1	..	..	..	..	..	..	..
Type 6 ..	1·7	..	..	2	..	..	..	..	..	..	..
Type 7 ..	1·3	..	3	..	1	..	..	..	..	..	..
Type 8 ..	2·2	..	..	2	..	..	1	..	..	..	..
Type 9 ..	6·2	..	..	..	..	..	1	..	..	1	1

D. SOLUBLE SALTS.

Several samples were analysed for their soluble salts. Qualitative analyses of extracts of typical soils show that sodium completely dominates the positive ions, while chloride is the most important of the negative ions (especially in the more saline soils), bicarbonate coming next in order of importance, while sulphate makes up the unimportant remainder. The chloride calculated as NaCl is therefore given as the index of salinity in Table XV.

Appreciable concentrations of salt may occur in the swamps of Type 6, even in the first foot; the surface soils of the low slopes, however, are relatively free from salt, as are those of the swamps of the crabhole type, where leaching of salt is helped by the cracking in summer. Concentrations of salt in subsoils are usually high, especially in the swampy areas. For example, sample 13c, at a depth of 20-26 inches, reaches 0.37 per cent. of sodium chloride. In spite of this salinity, this soil carried a fair growth of the annuals *Trifolium subterraneum* and *Hordeum maritimum* after being drained and top-dressed. A concentration of 0.35 per cent. was also reached at a depth of 24 inches in sample 161, the pan on which the vegetation depicted in Fig. 10 was studied.

These high concentrations of salt even on the slopes show that leaching is not very effective, and this may be connected with the fact that the average rainfall per wet day is low in this part of Victoria.

TABLE XV.—SALT CONTENT OF SOILS.

Low Slopes.			Crabholes.			Clay Pan (Type 6).		
Sample.	Depth.	NaCl per 100,000.	Sample.	Depth.	NaCl per 100,000.	Sample.	Depth.	NaCl per 100,000.
006a	0–7	13	270a	0–7	tr.	13a	0–9	45
006b	7–24	63	270b	7–26	8	13b	9–20	102
006c	36–42	237	270d	41–54	186	13c	20–26	370
014a	0–7	12	270f	66–90	437	161b	8–20	110
014b	7–16	20	271a	0–8	7	161c	20–27	353
014d	30–42	108	271b	8–24	58	171a	0–12	40
014e	60–72	150	271c	28–40	342	171b	12–24	67
019a	0–8	tr.	281a	0–8	10	170a*	0–10	12
019b	8–21	133	22c	15–24	9	170b*	10–18	17

* Bank corresponding to clay pan sample 171.

E. pH VALUES.

Reactions were determined by means of the quinhydrone electrode. The distribution of the pH values of the surface, subsurface, and subsoil is shown in Table XIV. It will be seen that pH values on the acid side of 6 are confined to the lighter surface soils—the stony rise brown loams (Type 1) and the lighter type of low slopes (Type 4), which are more easily leached. The alkalinity of the crabhole puffs (Type 7) is in marked contrast to the slight acidity of the other soils of the area. The next highest figure, 7.0 for the thistle zone soil (Type 3), is significantly higher than that for the adjoining slopes.

The word "subsurface" is used here to correspond roughly to the depth 10 to 24 inches; the pH generally rises by about a unit in going through this section, but the mean value lies close to 7.0 for most soil types, except Type 7 which is calcareous throughout. The deeper, calcareous yellow subsoils also have a similar reaction whatever the soil type may be. The frequency of pH values above 8.5 in the deep subsoil may well be due to exchangeable sodium.

TABLE XIV.—DISTRIBUTION TABLE OF pH VALUES (QUINHYDRONE ELECTRODE).

—	Mean.	4·5–5·0.	5·0–5·5.	5·5–6·0.	6·0–6·5.	6·5–7·0.	7·0–7·5.	7·5–8·0.	8·0–8·5.	8·5–9·0.
Type 1 (Stony rise brown loam)—										
Surface	5·5	1	6	6	1	..	..	..	..	..
Type 2 (Stony rise clay)—										
Surface	5·8	..	..	4	2	..	..	..	..	..
Subsurface	6.8	..	..	..	1	..	1	..	..	..
Type 3 (Thistle zone)—										
Surface	7·0	..	..	..	3	1	3	1	1	..
Subsurface	7·3	..	..	..	..	2	..	3	..	..
Subsoil	8·1	..	..	..	..	..	1	..	3	1
Type 4 (Light low slope)—										
Surface	5·8	..	2	10	7	..	..	..	..	..
Subsurface	7·4	..	..	..	..	1	2	3	..	..
Subsoil	8·2	..	..	..	..	..	..	2	3	2
Type 5 (Heavy low slope)—										
Surface	6·3	..	..	1	7	3	..	..	..	..
Subsurface	6·9	..	..	..	1	..	2	..	..	..
Subsoil	8·0	..	..	..	..	..	..	..	1	..
Bank of Pan and Bank complex— (Bank similar to Type 4)—										
Surface	5·9	..	1	..	3	..	..	..	..	..
Subsurface	6·8	..	..	..	1	..	..	1	..	..
Subsoil	8·2	..	..	..	..	..	..	..	2	..
Pan (Type 6)—										
Surface	6·5	..	..	2	2	7	1	..	..	..
Subsurface	7·3	..	..	..	..	..	3	2	..	..
Subsoil	8·1	..	..	..	..	..	..	1	3	1
Type 7 (Crabhole Puff)—										
Surface	8·0	..	..	..	..	..	..	3	3	..
Subsurface	8·5	..	..	..	..	..	..	..	2	3
Subsoil	8·5	..	..	..	..	..	..	..	1	2
Type 8 (Crabhole Depression)—										
Surface	6·5	..	..	..	3	2	..	..	..	..
Subsurface	7·2	..	..	..	..	1	2	2	..	..
Subsoil	8·1	..	..	..	..	..	..	1	1	1
Type 9 (Mountain soil)—										
Surface	6·0	..	1	6	8	1	..	..	..	..
Subsurface	6·9	..	..	..	1	3	..	..	1	..
Subsoil	8·8	..	..	..	..	..	..	..	..	2

F. EXCHANGEABLE CATIONS.

The analyses of the exchangeable cations of representative samples are given in Table XV. It will be seen that magnesium is the dominant ion in most of the mature types, while calcium is generally second in order of importance. This predominance of magnesium is invariable at the deeper levels, and is also well marked on the heavy surface soils 006a and 180a, though on the lighter surface soils (014a, 019a), including the immature soils (4011a, 408a), calcium is more important. Definite predominance of calcium seems to be confined, among the mature soils, to the calcareous puffs of the crabhole type (270a, 280a), though even here one of the two samples analysed shows quite a high figure for magnesium. Two samples from types fairly high in organic matter (305a, 56a), show calcium and magnesium in equivalent amounts.

Sodium is present in amounts varying from small values up to 14 per cent. of the total cations in the surface soil, and exceeds 20 per cent. in three of the deep calcareous subsoils (014e, 11e, 270e), all of which occur on the poorly drained plains and are quite saline. In the better drained and less saline subsoil from the mountain (56b), sodium reaches only 10 per cent. The lowest percentages of sodium are found in the well-drained soils on the stony rises (4011a, 408a) and on the friable and deeply cracked "puffs" of the crabhole and thistle-zone types (270a, 280a, 305a).

Potassium makes up only a small proportion of the total of exchangeable cations, and this proportion is higher in the surface than in the subsoil. If the doubtful assumption is made that exchangeable potassium is a measure of available potassium, then the amount of this potassium in the soils analysed is at a satisfactory figure for fertility.

Origin of High Value for Exchangeable Magnesium and Sodium.

The percentage of magnesium among the exchangeable cations is very high when judged by the standards of other countries. The basalts of the Western District certainly contain considerable amounts of magnesium, which may reach 11 per cent. of the rock (as MgO). But this fact can hardly be accepted as the reason for the predominance of magnesium among the exchangeable cations in a soil that has been so long exposed to the weather. Exchangeable magnesium is in fact high throughout those sections of south-eastern Australia which have the Mediterranean type of climate, whatever the parent material of the soil may have been. The proportions of cations given above are in fact very similar to those found in the course of surveys in the Murray Valley (e.g., Taylor and Penman, 1930) and the high magnesium is found even in Tasmania (Taylor and Stephens, 1935). Prescott (1931, p. 29) commenting on this suggests that "This relatively high proportion of exchangeable magnesium is probably to be related to the accession of magnesium salts to the soil as cyclic salt." The importance of cyclic salt in this part of the Western District is indicated by the occurrence of salt lakes.

While the winter is showery, the rainfall is not very high, and the natural drainage is so poorly developed that salts can accumulate in the subsoil.

There is very little information in the literature as to the connection of high magnesium values with the fertility or the tenacity of the soil. The soils on the slopes (e.g., 006a) and in the non-calcareous swamps (e.g., 180a) to the north of the mount, and in the swamps (e.g., 171a) to the south of the mount, have a poor texture, and dry to very hard clods. There is, however, no evidence that these properties are due to the high Mg; they could be accounted for by the high content of clay of these soils and to their lack of saturation with bases; the more saturated or calcareous soils such as the thistle-zone and crabhole types are much more friable although they are high in clay. Hungarian workers (Kreybig, 1935) have described magnesium soils which are equal in texture to normal calcium soils but which appear to be associated with sensitivity to drought.

TABLE XV.—EXCHANGEABLE CATIONS.

—	Sample Number.	Depth (Inches).	Exchangeable Ions. Per cent. of Total. Ca.	Mg.	K.	Na.	Total in milliequiv. per 100 gm. Oven-dry Soil.	pH.	Per cent. Clay.
Type 1 (Stony rise brown loam)	4011a	0–5	58	29	9	4	9·6	5·3	13·7
	408a	0–3	54	31	10	4	4·1	4·9	..
Type 3 (Thistle zone) ..	305a	0–8	46	48	2	4	39·1	6·4	53·7
Type 4 (Lighter low slopes)	014a	0–7	39	42	8	11	3·6	5·4	10·4
	014b	7–16	30	52	3	15	16·5	6·4	38·6
	014c*	60–72	35	40	1	23	45·0	8·4	56·6
	019a	0–8	51	36	5	8	3·9	6·1	..
	019b	8–21	24	60	4	11	30·0	8·0	..
Bank of Pan-and-bank complex surrounded by Type 4	11c*	39–42	30	46	3	21	38·3	8·6	..
	170a	0–10	45	35	5	14	6·2	5·3	17·7
	170b	10–18	32	49	3	16	20·6	5·5	46·0
	170d*	40–48	35	50	2	13	26·5	8·0	..
Type 5 (Heavier low slope)	006a	0–7	27	57	5	11	23·1	6·0	41·8
	006b	7–24	25	58	3	14	23·6	7·0	42·8
Type 6 (Clay pan) ..	171a	0–12	36	52	3	9	31·9	6·8	46·7
	171c	24–30	36	51	3	10	36·5	7·6	60·1
	180a	0–7	27	56	8	9	24·8	6·6	55·9
	180b	7–14	24	58	7	11	29·5	6·5	61·8
Types 7 and 8 (Crabhole complex)—									
Puff	270a*	0–7	69	25	4	2	44·6	8·1	58·0
	270b*	7–26	51	39	4	6	42·0	8·6	57·1
	270c*	54–66	15	61	3	21	34·0	8·6	48·6
Depression ..	271a	0–8	58	32	4	6	37·4	6·9	46·3
Puff	280a*	0–8	53	40	2	5	42·4	8·3	51·7
	280b*	8–20	50	40	2	8	50·2	8·6	50·3
	280d*	30–40	36	52	2	10	48·0	8·2	..
Depression ..	281a	0–8	37	51	3	9	15·4	6·4	34·1
Type 9 (Mountain soil) ..	56a	0–5	42	43	7	8	25·8	6·4	40·4
	56b*	27–33	38	51	1	10	50·9	8·8	44·2

* Soils thus marked are calcareous.

Sodium is probably added as sodium chloride in the rain. It is an open question whether the 10 per cent. or so of sodium in the cations of the surface soil plays a part in causing a poor texture, but the deep calcareous subsoils undoubtedly owe their impermeable nature partly to the high amount of replaceable sodium.

G. Chemical Composition of Colloidal Fractions.

The fraction less than one micron (0.001 mm.) in diameter was isolated from five selected soils. Four of these were dispersed directly by shaking with dilute NaOH, while the calcareous soil 270e was first treated with a slight excess of dilute HCl and then washed free of acid before dispersing with alkali. The suspensions were allowed to settle in tall cylinders for four days, then siphoned off to a depth of 28 cm. from the surface. This treatment was repeated on the residue, and the combined liquids from three such treatments were evaporated to dryness. The solid was then repeatedly washed with $\frac{N}{50}$ HCl, using a centrifuge, then washed with aqueous alcohol and dried at 105°. While the extraction of colloidal matter by this method was not complete, enough was obtained to justify one in regarding it as a fair sample of the total colloid.

Some of the results of total chemical analysis are given in Table XVIa. Besides the elements reported here, the samples contained considerable magnesium (up to 2 per cent. MgO) but traces only of calcium. This agrees with the general principle that calcium occurs mainly as an exchangeable ion, while magnesium occurs also as a non-exchangeable ion. Titanium is fairly high in the clays, as it is in the parent rocks.

Chief interest, however, attaches to the three main constituents —silica, alumina, and ferric oxide, molecular ratios of which are collected in Table XVIb. The silica-alumina and silica-sesquioxide ratios fall into two classes; the dark brown soil from the stony rise (401a) is much richer in sesquioxides than the other four samples, which are all from profiles of grey, relatively mature soils, and are highly siliceous.

In view of the confused state of soil nomenclature to-day, one would hesitate to assign the more mature soils (types 3 to 8) to any of the great soil groups of the world. While it is probably true, as pointed out by Marshall (1935) that mere silica-sesquioxide ratios give little information as to the true nature of a clay, it is clear that these soils belong to the markedly siliceous class. The existence of a podzolizing process is indicated by the relatively low pH values of the surface soils, by the presence of iron concretions, and by the more siliceous nature of the surface soil (170a) than the subsoil (170c); but these soils are far from being podzols.

The contrast between the relatively ferruginous clay of the rises and the siliceous clay of the slopes and swamps is very interesting. Such a difference must be due either to a different kind of weathering or to the erosion of siliceous surface material from the rises, followed by its deposition on the slopes and swamps. It is possible that the better drainage and the greater content of organic matter on the rises might result in the formation of a less siliceous clay than is formed on the slopes. If this were the case, one would expect to find some of this less siliceous clay deposited also around the edge of the rises in the "thistle zones"; but in fact the clays of this type are typically siliceous (e.g., 305a). If erosion alone is the cause of the difference, one must regard the stony-rise soils as undergoing a process of podzolization, leading to a siliceous surface and a relatively sesquioxidic subsoil; if the siliceous surface were then continually eroded, the resultant soil would be partly a residual subsoil and partly a freshly weathered material derived directly from the basalt. Such soil might have a silica-sesquioxide ratio of about 2, as has the sample here quoted. Whatever be the true explanation of the facts, it is clear that erosion has played, and still plays, an important part in determining the nature of the soil of this area. When the rises have been further reduced in slope as has occurred at some points, eventually the same grey type of soil forms on them as is characteristic of the rest of the plains.

TABLE XVIA.—CHEMICAL COMPOSITION OF COLLOID FRACTIONS.

Type.	Sample Number.	Depth (Inches).	Per cent.			
			SiO_2.	Al_2O_3.	Fe_2O_3.	TiO_2.
1	401a	0–8	42·6	25·3	14·7	1·8
3	305a	0–8	49·6	20·4	11·3	1·5
4–6*	170a	0–10	49·6	18·9	8·9	3·4
4–6*	170c	18–36	49·1	22·2	11·6	2·8
7	270e	54–66	51·4	22·5	11·4	1·6

TABLE XVIB.—MOLECULAR RATIOS OF SILICA, ALUMINA, AND FERRIC OXIDE.

Type.	Sample.	Depth (Inches).	$\frac{SiO_2}{Al_2O_3}$.	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$.	$\frac{Al_2O_3}{Fe_2O_3}$.
1	401a	0–8	2·86	2·08	2·7
3	305a	0–8	4·12	3·04	2·8
4–6*	170a	0–10	4·44	3·41	3·3
4–6*	170c	18–36	3·75	2·81	3·0
7	270e	54–66	3·89	2·93	3·1

* This sample is from a bank in pan-and-bank complex surrounded by soil of Type 4.

H. Analyses of Colours.

Table XVIII. contains the analyses of the colours of representative soils of each type. The dry soil was ground to pass a 1 mm. sieve and stuck with duco on to a disc of bristol board. This disc was clamped on to an axis together with four larger discs of standard colours, and the whole was rotated rapidly enough to avoid flickering. The relative areas of the standard discs were varied until a match was obtained. This is the method recommended by Taylor (1935). The standards referred to in Table XVIII. are printed by the Munsell Color Company, and are described by the United States Bureau of Standards as follows:—Black, neutral, 1/-; white, neutral, 9/-; yellow, 8/8; red 4/9.

The table shows the existence of six different colours in the surface soils, viz., 1; 2 and 3; 4; 5 and 6 and 8; 7; 9. Different samples of one type agree very well with one another. The table brings out both the darkness and the brownness of the types richest in organic matter (1, 9). These types are distinguished by having less white than yellow or red. Among the other types which are of various depths of grey, the loamy type 4 has much the lightest colour. The values for type 7 (crabhole puff) give a false impression of its appearance in the field; these figures really represent the mean of a black soil and white calcium carbonate. The contrast between the black subsoils of the thistle zone and the grey subsoils of the other types is also interesting.

Table XVIII.—Analyses of Colours of Soil Types.

Type.	Number of Samples.	Percentage of			
		Black.	White.	Yellow.	Red.
Surface Soils—					
1	2	83	2·5	6	8·5
2	3	83	7	5	5
3	4	84	6	5	5
4	3	63	16	10	11
5	2	74	10	8	8
6	1	75	10	9	6
7	3	74	15	6	5
8	3	77	10	7	6
9	6	88	2	4	6
Sub-surface—					
3	2	87	7	3	3
4, 5	3	69	12	11	8

VI. Note on the Origin of "Crabholes."

The crabhole type of formation here described has been noted in many parts of Australia, sometimes under other names such as "gilgai" "melon-hole", and "Bay of Biscay". It has been mentioned by Prescott (1931, p. 15), who reproduces a section due to H. N. England, of a typical crabhole formation in the

Riverina district of New South Wales. The rough section reproduced here (Fig. 6) is essentially similar to England's.

The biggest areas of the crabhole complex occur in the Wimmera (Victoria) and the Riverina districts, the parent material being an unconsolidated sediment rich both in clay and in calcium. Crabhole formation also occurs directly on the Newer Basalt at Natte Yallock, near Avoca (Victoria), where it occurs on slopes as well as on flats, and often with basalt boulders lying on the surface. The formation in the area described in this paper has developed partly from basalt and partly from the wash from the slopes below the stony rises.

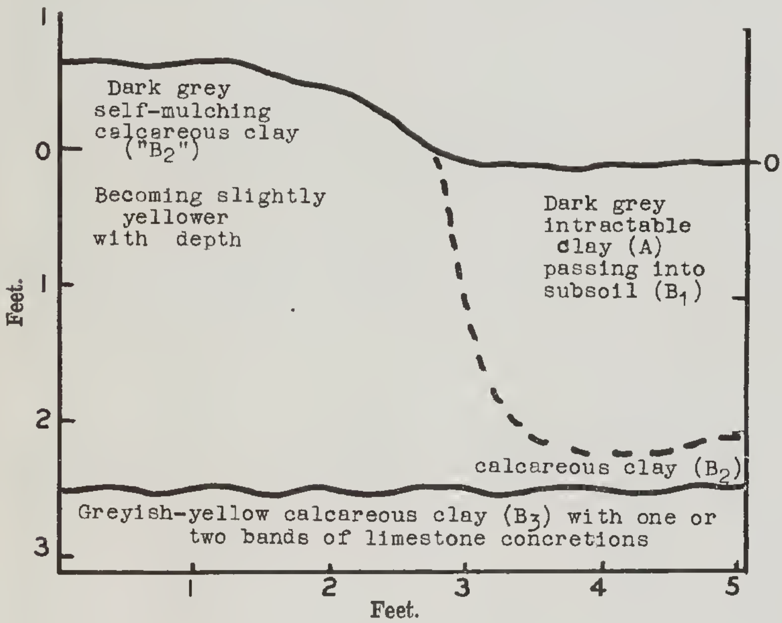

Fig. 6. Section through Crabhole Complex

Prescott points out that the districts in which "crabholes" occur are liable both to drought and to flooding. The climate also has been able to produce only a moderate degree of leaching, so that calcium carbonate is present throughout in the subsoil, and comes to the surface in the puff. Such an association of parent material and climate would be expected to recur in other parts of the world, and it is curious that so few reports of this complex have appeared elsewhere. The structure of the puff type of soil, however, appears to resemble that of the "adobe soils" in the west of the United States of America described by Smith (1933).

While no attempt is here made to put forward a comprehensive theory of the origin of crabholes, some of the data obtained should be useful in helping to solve this problem.

It is an interesting fact that, while swampy patches occur naturally over a considerable part of the area here surveyed, only a small proportion of these patches have given rise to crabhole formation. Apparently, at least two conditions are required to form crabholes on this parent material. Firstly, the proportion of sand in the soil must be below a certain maximum figure; and secondly, where this first condition is satisfied, the swamp must be a basin from which there is no definite outlet. Where the swampy patches occur along a line where water flows during wet periods the complex that is developed is of the "pan and bank" type.

The calcareous nature of the puff indicates that it is really a B horizon which has in some way lost its cover of A horizon and been pushed up. This is conveyed by England's section already referred to, which shows an A horizon only in the depression. This conclusion is reinforced by a comparison of the mechanical analyses of pairs of adjoining puff and depression. The depression is sandier, to a depth of two feet.

Table XVIII. refers to two pairs of puff and corresponding depression in the surveyed area; two other pairs collected by one of the authors are also included for comparison, one from Salisbury (Victoria) being typical of the sedimentary area of the Wimmera, while that from Natte Yallock has already been referred to.

It is noticeable that puffs occur only on soils that are clayey enough to form wide deep cracks in the summer. This is strikingly shown in the Mount Gellibrand area, where the gradual decrease in the concentration of sand in the soil is accompanied by an increasing tendency to crabhole formation in the swamps. As the map shows, the southern and eastern sections are free from "crabholes" and the biggest extent of them is in the north-west, where samples 270 and 271 are typical. The other case quoted—280-281 in the south-western section—must represent the upper limit of sandiness, beyond which crabholes cannot form. In general, the crabhole complex is found only when the surface soil of the surrounding slopes contains less than 50 per cent. of total sand. The sample 280-281, however, is close to slopes containing 30 per cent. of coarse sand and 40 per cent. of fine sand in the surface soil; the higher concentration of clay in this crabhole complex is a good example of the exluviation (see 113) of the finer fractions from the slopes. This patch of crabholes is too small to be given its proper sign on the soil map.

One can draw up some such scheme as the following, to account for the formation: When the soil dries and cracks, pieces of the surface fall down the cracks, adding to the bulk of subsurface and subsoil. When this becomes wet again, it must swell; and now that the subsoil has received extra material, it will exert pressure sideways, and upwards. In time this subsoil bursts through to form the surface of a "puff", leaving the former A horizon partly in the depression (where it may still be seen) and partly mixed up with the mass of subsoil in which it is lost, since B horizons are generally deeper than A. Vageler (1933) attributes the uniformity of the profiles of tropical and subtropical black earths on clay flats to this mixing up by alternate cracking and swelling. The tendency of the subsoil to swell is shown by the fact that drainage channels (4 inches deep) cut through this land are liable to close up through the appearance of a new puff; and even after the land has been levelled (i.e., the calcareous clay is distributed over all the surface), the puffs still assert themselves, as can be seen if one examines the aerial photograph of a field ploughed and sown to grass several years ago. The depression generally contains more organic matter than the puff; this may be due to the fact that the roots of many plants cannot withstand the cracking of the puffs.

The correlation of *Medicago hispida* with this formation is remarkable. This burr medick is often the only plant to be found growing on the puffs; and the northern paddocks which contain the crabhole areas are also marked by the presence of this burr. It is not known if this association is connected with the marked contrast in pH of the puffs and the other soil types.

TABLE XVIII.—PROPERTIES OF COMPONENTS OF CRABHOLE COMPLEX.

Where Sampled.	Description.	Depth (Inches).	pH.	Sand (Per cent.).	$CaCO_3$ (Per cent.).	Organic Carbon (Per cent.).
Moolerie ..	Puff ..	0–8	8·3	23	4·5	1·01
	(Sample 280)	8–20	8·6	22	10·7	0·78
	Depression ..	0–8	6·4	46	0·0	1·68
	(Sample 281)	8–20	7·2	36	0·0	1·01
Turkeith ..	Puff ..	0–7	8·1	17	9·0	2·19
	(Sample 270)	7–26	8·6	18	10·6	1·19
	Depression ..	0–8	6·9	30	0·0	3·11
	(Sample 271)	8–24	7·6	20	tr.	1·46
Salisbury ..	Puff ..	0–7	8·2	20	*	..
		7–16	8·2	24	..	..
	Depression ..	0–7	7·1	43	0·0	..
		7–24	7·7	30	..	..
Natte Yallock ..	Puff ..	0–2	8·5	18	*	..
	Depression ..	0–2	6·2	34	0·0	..

* These soils are calcareous, especially that from Natte Yallock.

VII. Mineralogy of the Sand Fractions.

The gravel fractions (over 2 mm.) and coarse sand fractions (2–0.2 mm.) were examined under the binocular microscope, and in the mountain and stony rise soils, an approximate estimate of the composition of the coarse sand was made by counting the number of grains of each mineral species present in a sample of

200. The percentage of each mineral by volume in the fine sand (0.2–.02 mm.) was determined as described in a previous paper (Nicholls, 1936).

Numerous examples of each soil type were examined, and no significant mineralogical difference in the composition of the fine sand was found between individual samples belonging to the same type, except in type 1 (see Table XIX.), where the high variability is only to be expected. Results are therefore given in Table XX. as an average for the whole type. The samples were taken from varying depths in the soil profile, in some cases a complete profile being examined to a depth of 5 feet. The figures quoted in Table XX., however, are compounded using only one mean figure for each profile; the average for types 4 to 8, for example, is the average of five figures, these being the means of profiles 014, 170-1, 180-1, 270-1, and 280. The amount of sand in the soil changes with depth, but the mineral composition of this sand is remarkably constant (see Table XXI.). One important variation is shown by the number of sponge spicules present, which is high in surface soils and falls rapidly with increasing depth, but since these spicules are organic remains and not soil minerals, they have been omitted in the

TABLE XIX.—MINERAL COMPOSITION OF FINE SAND OF VARIOUS SAMPLES OF TYPE I.

Number of Grains of Principal Minerals in Sample of 500.

No.	400a.	4001a.	4011a.	402a.	403a.	405a.	406a.	408a.	409a.
Quartz	275	194	169	228	260	190	261	174	292
Plagioclase ..	73	87	132	93	97	103	74	93	59
Iron oxide ..	50	138	102	71	74	57	61	82	64
Augite	44	26	41	76	39	60	39	68	20
Olivine	9	18	23	18	4	20	15	23	10
Rock	23	35	29	11	21	25	20	29	20

TABLE XX.—AVERAGE PERCENTAGE VOLUME OF IMPORTANT MINERALS IN FINE SANDS.

Soil Type.	1. Stony Rise Loam.		3. Thistle Zone.		4–8. Slope and Swamp Soils.		9. Mountain Soils.	
Quartz	50·3	(4·4)	86·8	(0·6)	93·7*	(0·1)	76·6	(2·2)
Plagioclase ..	**19·3***	(1·8)	**8·7**	(1·7)	3·9	(0·2)	**10·0**	(0·7)
Iron oxide ..	**8·4***	(1·5)	1·7	(0·6)	1·2	(0·1)	3·3	(1·0)
Augite	**12·3***	(1·5)	**1·0**	(0·1)	Trace		**0·4**	(0·15)
Olivine	**2·2**	(0·4)	0·8	(0·3)	0·5	(0·05)	**1·5**	(0·4)
Basalt	**7·6***	(1·1)	**0·3**	(0·15)	Trace		..	
Basaltic glass ..	..		..		..		**7·7***	(1·7)

NOTE.—Figures in black type are significantly higher than those for mature soils (Types 4–8).
Percentages significantly the highest for each mineral are marked with asterisk.
Figure in parentheses are the standard errors of the means.

TABLE XXI.—MINERAL COMPOSITION OF FINE SAND OF TYPICAL CRABHOLE PROFILE (270).

Number of Grains in Sample of 500.

Horizon No. / Depth	a 0–7″.	b 7–26″.	c 26–41″.	d 41–51″.	e 54–66″.	f 66–90″.	g 120″.
Quartz	390	} 449	458	462	458	453	{ 392
Plagioclase	58	}					{ 49
Iron oxide	24	23	20	18	19	30	40
Augite	1	..	2	3	4	..	1
Olivine	8	9	6	5	4	8	6
Rock	..	..	..	..	1	..	..
Zircon	5	5	5	5	5	4	3
Tourmaline	5	6	3	5	4	4	4
Leucoxene	1	6	5	1	2	..	5
Epidote	..	..	..	..	1	..	..
Sponge spicules	8	2	1	1	2	1	..

calculation of results. Samples from different depths of the same profile have then been incorporated in the calculation of the average.

The standard error of the mean of the results for each type has been calculated in the usual way, on the assumption that each is a random sample of a uniform population.

Great difficulty was found in distinguishing with certainty between the quartz and the labradorite present in these soils. The refractive indices of the two are almost identical, and the felspar often appears quite clear, untwinned and with no trace of cleavage. Methods of staining were tried for the separation of these minerals, but hydrofluoric acid was necessary to attack the felspar, and no concentration could be found at which all the felspar was attacked and all the quartz left untouched. When doubtful cases arose, therefore, the axial figure was determined in order to identify the mineral. It was found quicker to determine the quartz-felspar ratio by a separate count of 100 grains, in which the axial figures were determined when necessary.

A. DESCRIPTION OF MINERALS.

Type 1 (Stony Rise Brown Loam).

The gravel of these soils consists of greatly decomposed basalt fragments, with a few grains of quartz and buckshot.

Coarse Sand—

Quartz (61 per cent.).—Generally sub-angular, sometimes rounded. Iron-stained along cracks and in hollows. Inclusions common; iron oxide, rutile needles, apatite, zircon, tourmaline and fluid inclusions have been noted, the last often arranged in bands in the manner characteristic of reef quartz.

Basalt (39 per cent.).—Fragments of crystalline basalt, highly decomposed.

Augite (trace).—Irregular broken fragments, with "titanium violet" tinge. Appear to be quite undecomposed.

Buckshot (trace).—Rounded and polished ironstone pellets.

Fine Sand—

Quartz.—As in coarse sand.

Plagioclase.—Irregular fragments, quite undecomposed. Refractive index about 1.565, indicating labradorite.

Augite.—As in coarse sand.

Iron Oxide.—Magnetite or ilmenite. Irregular grains and fine needles, usually fresh.

Basalt.—As in coarse sand.

Olivine.—Irregular fragments, characteristic olivine green with deep red-brown iddingsite border. Quite fresh.

Zircon.—Rounded grains or crystals with rounded terminations.

Tourmaline.—Rounded grains and short, stumpy prisms with rounded edges. Blue and brown.

Hyalite.—Water-clear, irregular fragments.

Broken fragments of the spicules of *Spongilla* are also present.

Type 2 (Stony Rise Clay).

The gravel and coarse sand of these soils contain only quartz and buckshot. The fine sand minerals are similar to those of Type 1, but the rock fragments, augite, and plagioclase grains are much smaller and show more alteration. Small rounded grains of leucoxene are also present.

Type 3 (Thistle Zone Soils).

Usually, the gravel and coarse sand of these soils contain only quartz and buckshot, but small fragments of decomposed basalt occur occasionally. The fine sand contains the same minerals as Type 1, but the augite and plagioclase show signs of alteration. Rutile, epidote, andalusite, and leucoxene have been observed in soils of this type.

Types 4-7 (Low Slope and Swamp Soils).

The gravel and coarse sand fractions of these soils consist of quartz grains with a varying amount of buckshot. Electromagnetic separation shows that an average of 2 per cent. of the coarse sand of the low slope soils is buckshot, but the percentage in different samples varies considerably and in some cases reaches 7. The fine sand contains the same minerals as Type 1, with the exception that augite occurs only in samples taken in close proximity to basalt, as when a basalt boulder (or "floater") was encountered during sampling (e.g., Table XXI., Horizons c, d, e), or when the horizon sampled rested on basalt bedrock. In such cases, the plagioclase grains are fairly large and fresh, but normally the plagioclase of these soil types consists of extremely small and somewhat rounded grains, much decomposed and sometimes almost completely converted to secondary material. Rutile, epidote, andalusite and sillimanite occur occasionally in these soils, and small rounded grains of leucoxene are also present.

Type 9 (Mountain Soils).

The gravel of these soils contains greatly decomposed fragments of scoria, and of vesicular basaltic glass, with a few rounded quartz grains. In the locality mentioned on page 82, large pebbles of quartz and sedimentary rock occur. Grains of buckshot also occur, but are very rare.

The coarse sand contains quartz (63 per cent.), scoria and basaltic glass (34 per cent.), olivine (3 per cent.), and a trace of augite and buckshot. Augite was observed only from samples taken near types of basalt, or on the central basalt plug. The olivine occurs mainly as perfectly formed crystals up to 5 mm. diameter. These have a transparent red-brown appearance, but broken edges show the characteristic olivine green with a red-brown iddingsite border.

The minerals of the fine sand are like those of Type 1, except that instead of fragments of crystalline basalt, splinters of basaltic glass occur. These are irregular in shape, the conchoidal fracture giving exceedingly sharp edges. The glass is light yellow to deep brown in colour, often containing bubbles, usually quite isotropic but with some fragments showing signs of devitrification. A few specimens show needles of iron oxide and felspars already crystallized. The plagioclase of these soils is usually in the form of irregular fragments, but flat rhomb-shaped crystals occur which show very little cleavage, and in which the twinning is visible only when the crystal is turned on edge. The refractive index of these crystals is the same as that of the irregular grains.

B. Origin of the Minerals.

The most striking feature of the minerals in the sand fractions is the abundance of non-basaltic material, chiefly quartz. This quartz, which is characterized by inclusions such as rutile and zircon, and which appears rounded and water-worn, could not have crystallized from the basaltic magma, and the grains of zircon, tourmaline, andalusite, &c., which are associated with the quartz, obviously represent foreign material. The most likely source of this material is the volcanic ash, since, as has been stated, the explosive rocks of Mt. Gellibrand contain considerable percentages of included quartz and other non-basaltic minerals, and the proportion of these foreign minerals was probably higher in the fine material which fell over the plains. The importance of this explosive material is indicated by a comparison of the sand percentages of soils from the Mt. Gellibrand area with those of basalt soils from other parts of the western plains (such as Woorndoo, below), taken several miles from the nearest volcanic cone. For example:—

	Coarse Sand.	Fine Sand.
	%	%
014a (Mooleric Station) ..	23 ..	40
Basalt soil from Woorndoo ..	2 ..	22

The large fragments of olivine which occur in Types 4 to 7 probably came from the ash, since the explosive rocks of the mount show high percentages of large olivine crystals, and the occurrence of olivine in the soils of the plains is not connected with proximity to a stony rise.

It has been suggested elsewhere (Nicholls, 1936) that foreign material is commonly added to soils by the wind, and this is undoubtedly the case with much of the fine sand in the Mt. Gellibrand area. The non-basaltic minerals derived from ash and aeolian material would be expected to be similar, since they must be stable detrital minerals. Sponge spicules, however, have not been observed in the tuff, and therefore indicate the influence of wind transport. The coarser material is unlikely to have been transported long distances by the wind, and the sand percentages quoted above show that the addition of aeolian material cannot be responsible for all the non-basaltic minerals in the Mt. Gellibrand soils.

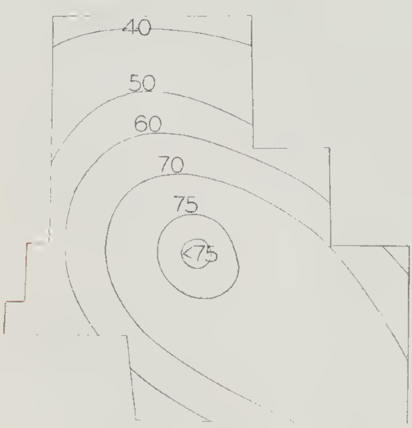

Fig. 7. Lines of equal percentages of total sand in top six inches.

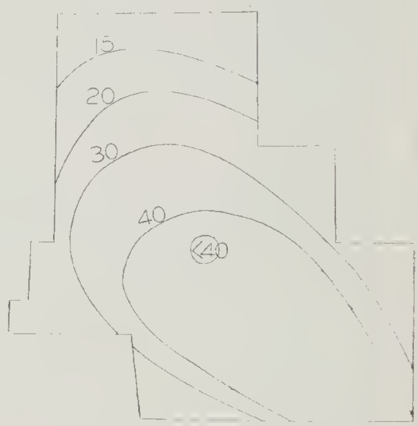

Fig. 8. Lines of equal percentages of coarse sand in top six inches.

The relation of the sand percentages of the soil to the volcano is shown by Figs. 7 and 8, which give respectively the total sand and coarse sand of the top six inches of soils from the low slope type. The lines of equal sand content form elliptical bands surrounding the mount, and the shape of the bands, like the shape of the contours of the mountain, shows that the prevailing winds during the period of eruption were from the north and north-west. The very sandy nature of the extreme south-east of the area is striking. The figures for coarse sand show greater regularity than those for total sand, possibly because of the inclusion in the latter of wind-blown material the distribution of which is not related to the mountain. The mineral composition of these sands is similar, but the percentage of total sand in the soil varies from 32 in the north to 75 in the south and south-east, while the corresponding variation in the coarse sand is from 7 to 41.

It seems clear that the basalt was covered by showers of ash, possibly in the form of mud, and that the lower-lying parts received additional ash washed off the stony rises. One might expect to find a point in the profile where the percentage of quartz sand suddenly fell on passing from the weathered ash to the weathered basalt. In general, however, no such sharp line has been found, so that it is impossible to estimate with certainty the depth of the original ash layer. The typical "crab-hole" profile, 270, however, provides a possible example of such a definite change; the sand percentages at a depth of 10 feet (coarse sand 1 per cent., fine sand 10 per cent.) are of the same order as are found elsewhere in deep subsoils developed over basalt without any complications from volcanic ash. The occurrence of non-basaltic minerals in such subsoils has been mentioned in a previous paper (Nicholls, 1936), and it is suggested that this is due to the washing of sand down cracks formed during the dry season.

Some profiles show remarkable changes in the sandiness with depth. For example, the percentage of coarse sand in profile 161 passes from a maximum of 26 at the surface to a minimum of 14 at 2 feet, and rises again to a second maximum of 23 at 3 feet, below which it falls again. Since at any point in the area the falls of ash must have varied in composition, and must have been accompanied by changes in the direction and force of the wind, one would expect some irregularity in the sandiness of the various horizons; this may well be the cause of the second maximum just quoted.

Apart from this banding, there is usually a marked decrease in percentage of sand, on passing from surface to sub-surface—invariably so in the lighter soils. There are various causes for this. The process of leaching under somewhat acidic conditions involves some washing down of clay. At the same time, the accumulation of wind-blown sand enriches the surface in the finer sandy material. An important process on the slopes consists of the loss of the finer fractions with the run-off water, a process called "exluviation" by Marbut. A good example of this exluviation may be seen in the development of the crab-hole complex in the south-west of the surveyed area (see Section VI.).

The basaltic minerals are prominent only in soils which are immature owing to the influence of topography, as would be expected since all the basaltic minerals with the exception of iron oxide belong to unstable mineral species. The mountain soils show crystals of olivine and splinters of basaltic glass, but augite and felspar are not prominent, as the lava in the explosive rocks seldom crystallized sufficiently to give large crystals of these. The brown loams on the steeper stony rises show high percentages of augite, labradorite and olivine, and grains and needles of iron oxide. These minerals are often large and irregular, and appear unweathered. On the broader type of stony rise, the decomposition of the basaltic minerals has proceeded much further.

The thistle zone soils show a small percentage of augite and comparatively fresh labradorite, apparently due to washing of these grains down from the stony rise. These minerals are usually small grains, and show definite signs of decomposition. Further down the slopes the influence of the rocks of the rise is not apparent, and the minerals appear to have been derived from the tuff and the underlying basalt sheets. Apart from the high content of quartz, and occasional large olivine grains, derived from the ash, the minerals resemble those of the mature basaltic soils from the extensive plains further west. Basalt is indicated only by small and much decomposed grains of plagioclase, and by the small grains of stable iron oxide.

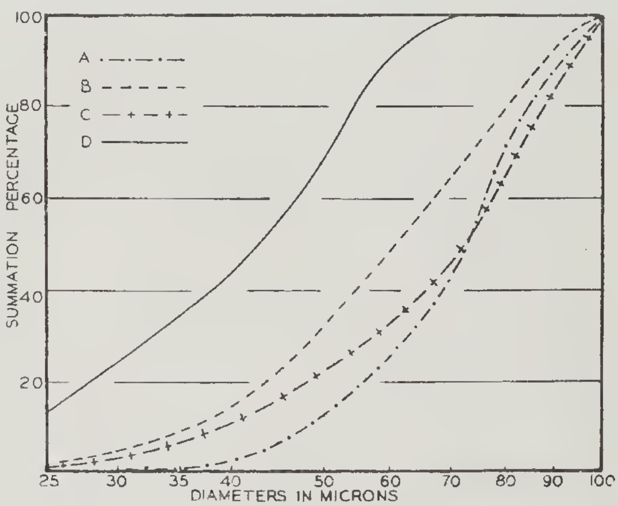

Fig. 9. Summation Curves, illustrating percentage composition by weight of fractions of various sizes in fine sand samples:—(A) Quartz in Tuff; (B) Quartz in sample 412a, directly above Tuff; (C) Quartz in several mature soils on the plains; (D) Iron Oxide in mature soils on plains.

The size distributions of certain minerals in the fine sands have been plotted in Fig. 9. Since the error in counting the few grains between 0.1 and 0.2 mm. in a sample of 500 is unduly large, the curves cover only the distribution between 0.1 and 0.025 mm. The original figures were the number of grains of 20, 25, 30 . . . 100 microns in a sample or mixture of samples of at least 200 grains. These figures were twice smoothed by the proeess of adding successive pairs, and the resulting figure for each grain size was multiplied by the cube of its diameter so as to give the proportion of each size by weight. The final figures were then plotted logarithmically as summation curves. Three of the curves represent the distribution of quartz (*a*) in the tuff, (*b*) in the soil formed directly over this tuff on the mountain, and (*c*) from a mean of several mature soils on the plain. These curves illustrate the absence of the finest material from the quartz in the tuff, and the presence of this material in the soils is evidence that it has been added by the wind.

The fourth curve (*d*) shows that iron oxide occurs only below 0.08 mm. diameter, as would be expected since the crystals in the basalt and the tuff are all small. The curve suggests that the iron oxide may show a maximum in the silt fraction.

Correlation Between Minerals and Fertility.

The soils on the rises and on the mountain (types 1, 2, and 9) are much more fertile than the soils of the low slopes and swamps. This is seen by the quality of the flora, and by the much greater quantity of organic matter in the former types. While the amount of phosphorus extractable with hydroehloric acid is also usually much higher in the former types, the correlation of fertility with the minerals of the fine sand is very striking. The soils on the rises and on the mountain are immature, and contain large amounts of easily decomposable primary minerals in their sand fraetions, namely labradorite and augite in the former case, and labradorite and basaltie glass in the latter. The soils on the slopes and swamps are relatively mature and devoid of useful minerals in their sand fraetions.

The surface of the minerals in the fine sand is much smaller than the surface exposed in the silt, and the mineral composition of the silt is therefore more important for plant fertility. The presence of a mineral in the fine sand fraction may, however, be taken as evidence that it exists also in the silt fraction.

Among types 3–8, differences in fertility are due either to physical causes—such as differences in drainage or in texture—or to differences in the degree of saturation with bases; the better lime status of the thistle zone soils and the crabhole puffs is important in raising their fertility. The soils of the thistle zones, however, also have a better supply of basaltic minerals which are continually replenished by the washing of very fine particles from the rocks of the rises.

VIII. Vegetation of the Area.

A. General Discussion.

During the progress of the soil survey, many observations were taken of the present flora of the area. Lists of species present in various localities were drawn up and numerous specimens collected. The results of these observations have been compared, and the owners of the properties have been consulted with reference to the treatments which have been given to various parts of the areas. These observations have made it practicable to draw up a generalized picture of the vegetation as a whole, in the light of the treatment it has received. No survey of the existing communities would be of value without a preliminary discussion of the ways in which they are modified by man, either by his control of the animal population living on the vegetation, or through his modification of the soils by drainage, or the addition of phosphatic manures, or by the introduction of new plants which may be of value to the economic exploitation of the area.

From early photographs, and according to local tradition and records, the plains were originally largely covered by a herbaceous vegetation, much of which was coarse in character. Small trees (apparently chiefly Blackwood (*Acacia melanoxylon*) and Lightwood (*Acacia implexa*)) and bushes were common on the rises and it seems likely that larger trees may have been frequent on the slopes of Mt. Gellibrand. Fires followed by grazing removed these woody perennials quickly, and to-day very few remain. During recent years the lack of shelter has been remedied by the introduction of numerous plantations in various parts, whilst a large number of trees have been planted around the houses. Apart from these, the only shrubs or trees are one or two individual specimens of *Acacia armata* and *Solanum aviculare,* but the remains of an arborial species of *Banksia* were encountered in two places. With these exceptions, the entire vegetation to-day is herbaceous in nature.

The effect of the grazing animal on the herbaceous vegetation is extremely marked, and by no means uniform on the various soil types.

The properties have been used for carrying sheep for the most part, although a certain number of cattle are always kept, probably with the idea of dealing with the rougher grazing material such as the tussocks of *Poa caespitosa* which are very frequent in many sections. The sheep are very selective in their activities, showing a marked preference for the short, "sweet" herbage of the stony rises; naturally therefore they tend to camp on these regions which accordingly receive some extra amounts of organic manure from their droppings. They graze the vegetation of the low slopes quite freely, but pay very little attention to the *Poa caespitosa* tussocks. During the periods of the year when the amount of feed is relatively sparse they turn to the less nutritious, dry material, but, during the occupancy of the present owners, it has never been the policy to stock the areas to such an extent as to force the sheep to graze *Poa caespitosa* extensively.

Experience has shown that, in all the better-drained sections of the area, profound changes can be brought about in the balance of vegetation by the application of superphosphate as a top-dressing. This procedure has been adopted on a more or less modest scale over parts of the area. As a result, the proportion of clovers in the vegetation has risen markedly, and in general the grasses have also been directly or indirectly stimulated to an increased growth. Where the distribution has been carried out by means of a seed drill, the change in the herbage is sufficient to show up very clearly in the aeroplane photographs of certain paddocks. The top-dressing procedure has been most intensive on the slopes of the mount adjacent to the southern station where perennial rye grass was introduced many years ago and has been cultivated for both the production of seed, and the grazing of dairy cows. Other paddocks which have been top-dressed have been treated from time to time, but on these the progress has never been stimulated to such an extent as to oust the Danthonias and other native species from their dominant position in the better-drained parts. In paddocks on the low-slope types of soil where no top-dressing has been given, vegetation is partly open in character, bare spaces between the individual plants being frequent. It seems reasonable to suppose that this type of vegetation is the natural pasturage to which 80 or more years of grazing have reduced the original vegetation. The result of the addition of superphosphate is to diminish the amount of open space, both by increasing the vigour of the individual Danthonias and also by making the conditions more suitable for clovers and other annual species to develop on the bare spaces between the individual Danthonia plants.

In the parts of the area which are subject to flooding in winter, the vegetation takes a new form; tussocks of *Poa caespitosa* become increasingly frequent and many of the pans and swamps are relatively unproductive from the grazing point of view. Here a sustained effort has been made to improve the carrying capacity of the country by altering the conditions in various ways which lead to improved drainage and the development of more satisfactory plant communities. Several distinct methods of approaching the problem have been adopted. In the case of the larger swamps, shallow drains have been ploughed along the contours so as to collect the water as it runs off from the rises towards the lower levels (see Plate V., lower photograph), and in addition, drains have sometimes been made through the centre of the swamps (see Plate V, upper photograph). The marginal method is practised on the southern half of the area where the swamps are large, and of heavy clays which are somewhat acidic. The central drain method has been used largely on the northern half, and seems well suited to the crabholey type of clay which is self-mulching, and can absorb a considerable amount of water down the cracks before becoming water-logged. On some swamps it has been found necessary to adopt both methods. On "pan and bank" country, the method employed is to plough or dig through the banks wherever the water tends to flow over the bank from one pan to another during periods of heavy rain. The combined result of all these efforts has been to decrease the areas of badly-drained soil, and consequently to reduce the amount of land covered by the vegetation typical of such areas. Much of the drainage work is recent in date, and as the change in the vegetation takes place only slowly unless cultivation is actually invoked many of the wetter areas are in a transitional stage.

Some of the larger swamps have actually been drained and used for cultivation of oats, wheat, or grazing crops from time to time. This process has been largely confined to the northern half of the area where the crabholey type of soil has proved itself of value for this purpose. A certain number of weeds have been introduced as a direct consequence of these cultivations.

In view of these numerous ways in which man has influenced the herbaceous vegetation, it has not seemed advisable to do more than separate the plant communities into two types—one found on the situations which are badly drained, and the other on the better-drained regions. The areas occupied by each type show a fairly wide range of variations according to the intensity with which the various factors have been allowed to act upon them; and it is of some interest to indicate the way in which the frequencies of the various species increase or decrease according to differences in soil or in treatment.

B. Areas not Liable to Swamping.

Table XXII. gives a list of the plants which were observed in localities which are included in this category. The symbols in the various columns indicate the relative frequency of each species; wherever a symbol is enclosed in a bracket it is intended to indicate that the intensity of occurrence is somewhat localized. In the case of certain plants (particularly annuals) this localization is probably a direct result of different grazing treatments on different paddocks. For instance, if there were a palatable species of annual plant fairly uniformly distributed over the drained areas of several paddocks, and, during its period of flowering and seed production, some of the paddocks were grazed more intensively than others, then there would be a tendency for this species to be relatively scarce in the following season; conversely, lack of grazing during this critical period would increase the probability that the species would appear in abundance in the next year.

The floristic record for the mountain soil (Type 9) was derived from the paddocks on the top and upper parts of Mount Gellibrand where the land is used for grazing only. Paddocks on the middle or lower slopes on the south and eastern sides were not studied, as the practice of cutting grass hay, or taking crops of seed of Perennial Rye Grass has introduced divergences in the vegetation which would merely obscure the general issue. The soils of this type have been shown to be high both in phosphate and in primary minerals (see Tables X. and XX.). Their surface layers have a relatively satisfactory texture

TABLE XXII.—LISTS OF PLANTS ON SOIL TYPES CHARACTERISTIC OF DRIER PARTS OF THE AREA.

—	Mountain Soil.	Stony Rise Brown Loam	Thistle Zone.	Low Slope.
Cheilanthes tenuifolius	..	r.	..	..
Themeda triandra	..	..	..	(ab.)
Koeleria phleoides	..	..	..	r.
Festuca bromoides	ab.	f.	..	(f)
Festuca rigida	(f)	..	occ.	occ.
Bromus mollis	d.	d.	ab.	occ.
Briza minor	..	(ab.)	f.	f.
Poa caespitosa	occ.	..	..	small form occ.
Calamagrostis quadriseta	..	..	..	(occ.)
Calamagrostis filiformis	..	..	..	(ab.)
Dichelacne crinita	..	..	..	f.
Pentapogon quadrifidus	..	..	..	(occ.)
Stipa variabilis	occ.	f.	..	f.
Aira caryophyllea	(f)	ab.	f.	ab.
Danthonia geniculata	..	ab.	f.	ab.
Danthonia semiannularis	ab.	ab.	f.	ab.
Lolium perenne	ab.	..	..	(f)
Agropyrum scabrum	(f)	(f	..	occ.
Hordeum murinum	(f)	..	..	..
Hordeum maritimum	f.	..	f.	(occ.)
Juncus bufonius	..	occ.	..	occ.
Juncus capitatus	..	occ.	..	r.
Lomandra glauca	..	..	..	(occ.)
Bulbine bulbosa	..	..	..	occ.
Dichopogon strictus	..	..	..	(occ.)
Arthropodium paniculatum	..	..	..	(occ.)
Romulea bulbocodium	..	..	..	(f)
Rumex dumosus	occ.	occ.	occ.	..
Rumex acetosella	..	occ.	..	occ.
Rhagodia nutans	..	..	..	(occ.)
Trichinum spathulatum	occ.	occ.	f.	occ.
Trichinum macrocephalum	..	occ.	..	..
Stellaria pungens	..	..	..	(occ.)
Cerastium glomeratum	..	f.	..	..
Moenchia erecta	occ.	f.	..	..
Sagina apetala	..	f.	..	occ.
Polycarpon tetraphyllum	..	occ.	..	f.
Silene gallica	..	f.	..	occ.
Ranunculus arvensis	..	..	..	(f)
Drosera peltata	..	..	..	(occ.)
Crassula Sieberiana	..	ab.	..	(f)
Crassula macrantha	..	(ab.)	..	(f)
Acaena ovina	..	..	..	(occ.)
Acaena sanguisorba	..	..	..	(occ.)
Trifolium procumbens	(ab.)	ab.	ab.	f.
Trifolium minus	f.	f.	ab.	(f)
Trifolium tomentosum	occ.	(ab.)	f.	(occ.)
Trifolium cernuum	..	(f)	occ.	(occ.)
Trifolium glomeratum	(f)	occ.	f.	(occ.)
Trifolium subterraneum	f.	(f)	occ.	(f)
Trifolium striatum	..	r.	..	..
Trifolium angustifolium	..	..	..	r.
Medicago arabica	occ.	occ.	..	..
Medicago hispida	occ.	..	..	..

TABLE XXII—*continued.*

—	Mountain Soil.	Stony Rise Brown Loam.	Thistle Zone.	Low Slope.
Swainsona behriana	..	r.	..	..
Kennedya prostrata	..	r.	..	..
Geranium pilosum	..	..	..	occ.
Erodium cicutarium	f.	(ab.)	occ.	..
Erodium cygnorum	..	occ.	..	..
Oxalis corniculata	f.	ab.	ab.	f.
Linum marginale	..	..	..	(occ.)
Bredemeyera ericinum	..	occ.	..	occ.
Poranthera microphylla	..	occ.	..	(f)
Hypericum japonicum	..	..	..	(occ.)
Pimelea curviflora	..	..	..	(f)
Hydrocotyle callicarpa	..	..	..	(occ.)
Hydrocotyle laxiflora	..	..	..	r.
Eryngium rostratum	..	occ.	r.	ab.
Daucus glochidiatus	..	(ab.)	f.	(ab.)
Anagallis arvensis	..	..	..	occ.
Sebaea ovata	..	occ.	..	(f)
Cuscuta epithymum	..	..	..	(ab.)
Dichondra repens	(ab.)	(ab.)	occ.	(f)
Convolvulus erubescens	..	occ.	occ.	(f)
Myosotis australis	occ.	..	..	occ.
Marrubium vulgare	(f)	..	..	..
Solanum aviculare	..	r.	..	..
Veronica gracilis	..	occ.	..	occ.
Bartschia latifolia	..	occ.	occ.	(occ.)
Plantago coronopus	..	(f)	..	(occ.)
Plantago varia	occ.	(ab.)	ab.	(f)
Galium murale	occ.	occ.	..	occ.
Asperula conferta	(f)	occ.	f.	occ.
Sherardia arvensis	occ.	..	..	(f)
Wahlenbergia gracilis	occ.	occ.	..	f.
Lobelia pratioides	..	..	..	(ab.)
Velleia paradoxa	..	..	..	(occ.)
Goodenia pinnatifida	..	..	..	(occ.)
Brachycome exilis	..	..	..	f.
Brachycome decipiens	..	..	(occ.)	..
Calotis scabiosifolia	..	..	..	(f)
Gnaphalium purpureum	..	..	..	occ.
Gnaphalium japonicum	..	..	..	(f)
Helipterum australe	..	(ab.)	..	(ab.)
Helichrysum apiculatum	..	ab.	..	f.
Helichrysum scorpioides	..	..	..	occ.
Leptorrhynchus squamatus	..	occ.	occ.	ab.
Podolepis acuminata	..	..	..	(occ.)
Myriocephalus rhizocephalus	..	..	..	occ.
Calocephalus citreus	..	..	..	(occ.)
Craspedia uniflora	..	..	..	(occ.)
Craspedia chrysantha	..	..	..	(occ.)
Cotula coronopifolia	..	..	..	f.
Soliva sessilis	..	..	..	r.
Cryptostemma calendulaceum	(f)	f.	ab.	..
Cymbonotus Lawsonianus	..	..	occ.	(occ.)
Carduus Marianus	occ.	occ.	..	..
Carduus pycnocephalus	(ab.)	(ab.)	ab.	..
Centaurea melitensis	..	..	..	occ.
Microseris scapigera	..	..	..	(occ.)
Hedypnois cretica	..	..	f.	occ.
Hypochaeris radicata	occ.	occ.	f.	(occ.)
Sonchus oleraceus	f.	(f)	occ.	..
Sonchus asper	occ.	(occ.)	..	..

ab.—Abundant. (ab.)—Locally abundant. f.—Frequent. (f) Locally frequent. d.—Dominant. occ.—Occasional. (occ.)—Locally occasional. r.—Rare.

and the subsoils allow water to percolate downwards. As a result they are eminently suitable for growth of pasture herbage. Their vegetation is therefore a close one, and contains species which are indicative of high fertility such as *Lolium perenne, Carduus Marianus* and species of *Trifolium* in abundance.

The general vegetation of the stony rise brown loams (Type 1) is somewhat similar in nature, but as already noted, the grazing on these areas is particularly severe owing to the habits of the sheep which incidentally are also partly responsible for maintaining the level of fertility in the soil (see Section V., B.).

Both on the mountain and on the stony rises there are many patches where the presence of boulders leads to soil development of merely 1 or 2 inches. In such locations the plants are subjected to conditions of severe desiccation whenever rain is deficient for more than a few days, and atmospheric humidity is low. The species occurring in such situations are, first and foremost, the lichens and mosses which have not been identified, and then certain small annuals such as the two Crassulas (*C. Sieberiana* and *C. macrantha*), *Aira caryophyllea, Sagina apetala.* Here and there between boulders are deep crevices which have not been entirely filled with soil; in one such *Cheilanthes tenuifolius* was found.

Naturally there are areas showing every gradation in respect to soil depth, and consequently there are similar gradations in the vegetation from these communities of annuals to those which may be regarded as characteristic of the deeper brown loams. The species of the stony rise tops vary considerably according to the breadth of the rise; the list shown has been put together as typical of a rise on which there were numerous boulders and little indication that water was retained sufficiently to give rise to semi-swamp conditions.

The zone of black soils around the rises has already been described. Its deep, friable, self-mulching soil makes it an effective zone for growth, but the cracking which takes place in summer probably lowers the water content of the upper layers, and may result in physical damage to the shallower roots. This favours the deep rooted type of perennial or biennial, notably *Carduus pycnocephalus*, and the vigorous annual which is able to establish itself effectively and grow rapidly when the season breaks in the autumn. Small annuals and perennials with spreading root systems, e.g., Danthonias, are less frequent.

The low slope type of soil is occupied by such herbaceous perennials as are able to withstand the desiccation of the dry winds of summer, or by annuals, where such can effect establishment and produce seed readily. The perennial native grass species with relatively narrow and moderately xerophilous leaves are frequent, as are Composites with hirsute, light-reflecting leaves. On areas where no superphosphate has been added the perennial plants are relatively small, and are separated by several inches from one another. The intervening spaces are more or less colonized by small annuals among which clovers are relatively inconspicuous. Where the paddocks have been top-dressed, the individual plants of grasses are generally larger and closer together, while the clovers (especially *Trifolium procumbens* and *T. minus*) are the most important annual species.

In certain paddocks without phosphate treatment, *Eryngium rostratum* has come to occupy an important position. According to local tradition this is largely due to overgrazing in a year when this species seeded very freely. Where more vigorous growth has been stimulated among the herbage this plant although frequent is less abundant.

Cuscuta epithymum occurs on a wide range of host plants in some areas, it was not noticed on the vegetation of the "improved" paddocks, but this may be no more than a chance effect.

Lolium perenne is entirely absent from low-slope areas which have not been treated with superphosphate, but in the treated areas of the southern property the species is more prevalent, partly because at times a certain amount of seed has been distributed with the manure and partly because the level of soil fertility approaches that requisite for the progress of the species.

C. The Crabhole Complex.

As already described, these areas have two distinct soils, differing in elevation and in physical texture. The puffs of dark self-mulching soil are similar in nature to the thistle zones of the stony rises. Their flora is also very similar, deep-rooted perennials or biennials, such as *Carduus pycnocephalus, Danthonia semiannularis*, and *Poa caespitosa* being mixed with vigorous annual grasses and clovers such as *Hordeum maritimum, Bromus mollis, Trifolium procumbens*, and *Medicago hispida*. There are, however, numerous blank areas between the plants. The "crabholes" themselves support a denser vegetation which is apparently less heavily grazed by the stock. The following is a list of some of the plants more frequently found on these depressions:—

Poa caespitosa	*Trifolium minus*
Danthonia semiannularis	*Daucus glochidiatus*
Bromus mollis	*Asperula conferta*
Leptorrhynchus squamatus	*Wahlenbergia gracilis*
Lepturus cylindricus	*Helichrysum scorpioides.*

Most of the large areas of the crabhole type have been drained and ploughed, and either cultivated and used for cropping, or sown down to pastures with rye grasses, subterranean and other clovers.

D. The Moister Areas.

In wetter spots on the low slopes tussocks of *Poa caespitosa* increase in numbers, and in some regions juncaceous tussocks appear. Where "pan and bank" formations occur, the "pans" usually have a more aquatic type of vegetation with *Poa caespitosa* tussocks, whilst the "banks" bear low slope vegetation usually with many tussocks.

Fig. 10 shows an actual transect taken along a line passing from a low slope into a pan of the type characteristic of the southern half of the area. *Lobelia pratioides* is a constant feature of the pan areas, but is rare on the banks. The ordinary annual species are often incapable of establishing themselves in the pans; presumably this is partly due to the amount of water in the winter and partly to the tenacious nature of the clay soils. Aquatic annuals are unsuccessful owing to the long dry period in the summer. Some of the pans retain their water much longer than others, and in these the aquatic species are able to establish and maintain themselves more effectively. There is some diversity between the species to be found in various pans, but the following list contains most of the commoner forms found in the wetter areas:—

Potamogeton tricarinatus	*Juncus prismatocarpus*
Glyceria fluitans	*Juncus holoschoenus*
Amphibromus nervosus	*Juncus pauciflorus*
Lepturus cylindricus	*Juncus vaginatus*
Scirpus setaceus	*Juncus polyanthemos*
Heleocharis acuta	*Juncus plebeius*
Heleocharis acicularis	*Claytonia australasica*
Carex declinata	*Ranunculus rivularis*
Schoenus apogon	*Ranunculus parviflorus*
Juncella submersa	*Myriophyllum propinquum*
Aphelia gracilis	*Utricularia dichotoma.*

Some of the species on the list (such as *Potamogeton tricarinatus, Glyceria fluitans,* and *Myriophyllum propinquum*) are from areas in which water is artificially retained for stock purposes, others are from pans which are dry during part of the summer. As is usual in the vegetation of ponds with shelving banks the plants show a zonal arrangement round the margins. The drier land surrounding a typical wet clay swamp bears *Poa caespitosa* in large tussocks with some of the low-slope plants, among which appear *Lobelia pratioides, Ranunculus arvensis,* and *Juncus* spp., while *Trifolium cernuum* and *Lotus corniculatus* are occasionally present. The wetter side frequently has a marked belt of *Utricularia dichotoma,* and *Amphibromus nervosus, Heleocharis acuta* and *Heleocharis acicularis* are often abundant and extend for some distance on the deeper side. *Stellaria palustris* and *Ranunculus rivularis* appear at about this level in some pans, while in deeper water *Glyceria fluitans, Potamogeton carinatus,* and *Myriophyllum propinquum* occur in some cases.

As already noted, some of the large swamps have been drained by opening surface ditches; the resulting area has the heavy clay soil described as Type 6. This is not an easy substratum for

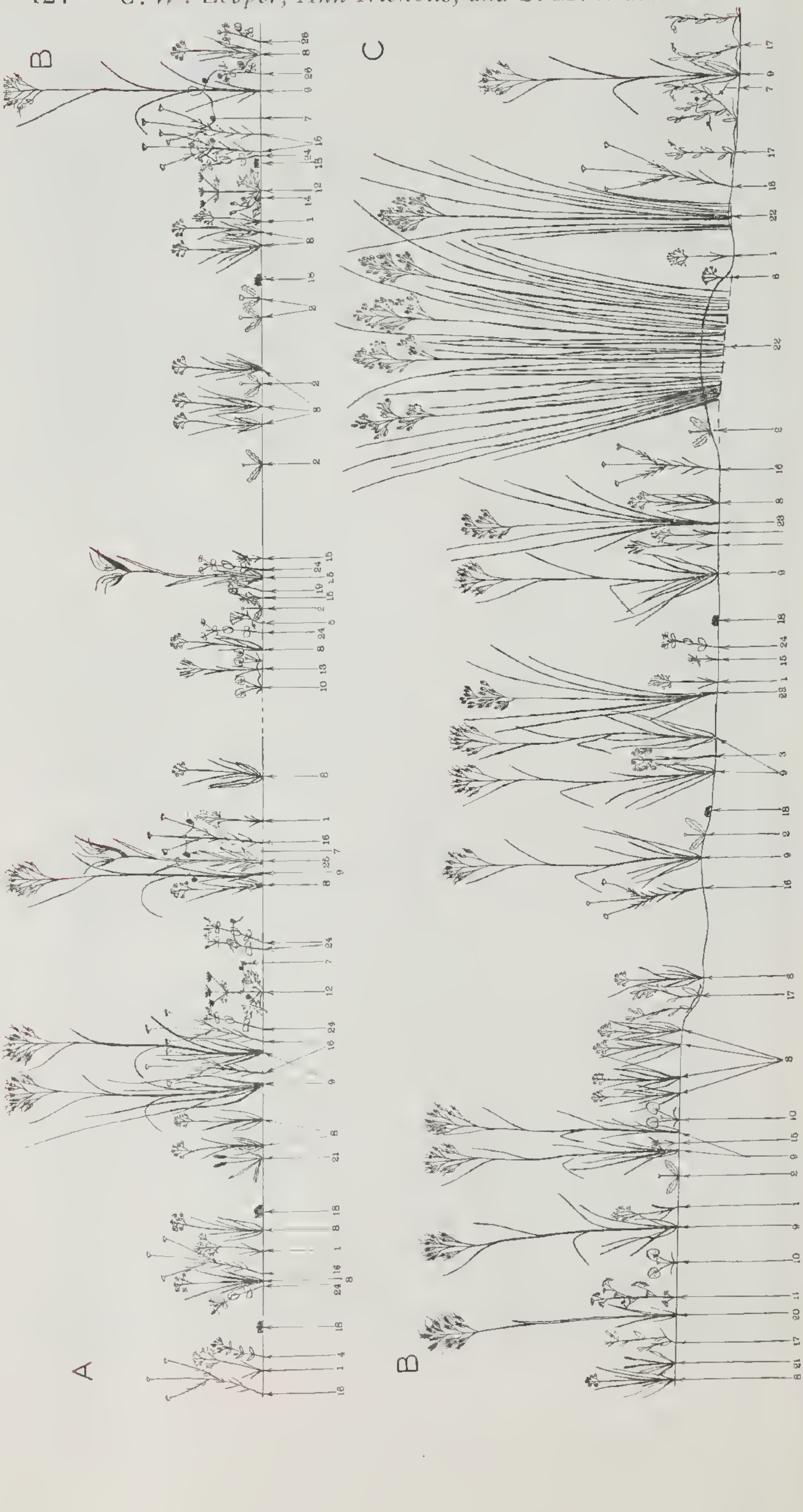

Fig. 10. Ten Metre Transect from Low Slope to Pan.

[J.R.F. del.

plant growth, and the resultant vegetation is poor. Salinity, low base saturation and high clay content may contribute to this result. Some of these "reclaimed" clay swamps have been ploughed up, but the low humus content of the clay renders them difficult to work. On one such swamp, which was cultivated and sown with perennial rye grass and subterranean clover, a vigorous response was obtained following the addition of sheep droppings gathered from beneath a shearing shed.

KEY TO FIG. 10.

Aira caryophyllea ..	.. 1	Hypochaeris radicata	.. 14
Brachycome decipiens	.. 2	Juncus capitatus ..	.. 15
Briza minor ..	.. 3	Leptorrhynchus squamatus	.. 16
Cerastium glomeratum	.. 4	Lobelia pratioides ..	.. 17
Convolvulus erubescens	.. 5	Moss	.. 18
Crassula macrantha	.. 6	Oxalis corniculata ..	.. 19
Cuscuta epithymum	.. 7	Pentapogon quadrifidus	.. 20
Danthonia geniculata	.. 8	Plantago varia ..	.. 21
D. semiannularis ..	.. 9	Poa caespitosa ..	.. 22
Dichondra repens ..	.. 10	Poa caespitosa seedling	.. 23
Drosera peltata ..	.. 11	Sebaea ovata ..	.. 24
Eryngium rostratum	.. 12	Themeda triandra ..	.. 25
Festuca bromoides ..	.. 13	Trifolium procumbens	.. 26

IX. Productive Use of the Land.

As it is commonly supposed that the Western District of Victoria is an extremely fertile area in respect to its soils, and also enjoys a very favorable climate, a brief critical survey of these factors from the standpoint of rural production in the area now under consideration is of some interest.

The climate is typical of the drier belt of the Western District which lies south of the Ballarat Plateau. The average monthly rainfall for the southern station, Mooleric, is given in Table XXIII. That for the northern station, Turkeith, is somewhat lower.

TABLE XXIII.—MONTHLY RAINFALL AT MOOLERIC (40-YEAR AVERAGE).

Month.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept	Oct.	Nov.	Dec.	Total
Inches rain	1·06	1·24	1·74	1·68	2·09	2·34	2·17	2·39	2·50	2·18	1·80	1·54	22·73

The summers are warm and dry and evaporation is high. The occasional rains which fall are of tropical origin and erratic; (thus the standard deviation from the mean for January is just under an inch, while the same figure holds for July, which has over twice the rainfall). The winters are cool and wet, and rain falls on the majority of days. Since surface soil temperatures remain too low for rapid growth during June, July, and August (the mean temperature being below 50° F.) the productivity of pastures during the succeeding spring depends very largely on an early break in the autumn. Good falls of rain in March and April allow perennials to make an early start and the annuals to establish themselves effectively before the surface soil temperature falls below 50° F., and there is then a rapid response to the higher temperatures in the following spring. The position is analogous to that studied in Adelaide by Trumble and Cornish (1936) who found that the production of pasture in any year was highly correlated with the rainfall in March and April. The "break" in the season at Mooleric—i.e., the date after which the ground remains moist enough for germination and growth—has varied during the period for which records are available between late January and late May.

The only soils which are inherently high in mineral fertility in our particular area, are the dark brown soils of the mountain (Type 9) and the tops of the rises (Types 1 and 2) and those of the thistle zone (Type 3). The rich mountain soils are confined to the top and upper slopes of the cone where cultivation is not easy. On these, intensive pasture production is practised on the southern and eastern slopes which are less subject to insolation and therefore more favorable for high-grade pasture species which are broader-leaved and less xerophytic than the native grasses. The brown loam of the rises and its attendant thistle zones would be worthy of cultivation, but the removal of a large number of boulders distributed on and in the former would be a Herculean task. Such a labour might be attempted by a rural community faced with either food shortage or land hunger, but it would be quite impracticable by one which must needs consider land utilization from an economic standpoint.

The crabholey soils (Types 7 and 8) have been developed into cultivable land wherever the existing areas extend over about 20 acres. They are fertile and capable of growing good cereal or hay crops, especially in seasons when winter rainfall over the area as a whole is not sufficiently heavy to cause serious flooding on these lower-lying patches.

The low-slope soils are in most cases free from boulders. Their inherent fertility is low in respect to both phosphorus and nitrogen; when the former deficiency is overcome by the use of superphosphate, and the latter by the secondary effect of the nodule bacteria on the roots of the legumes the resultant surface soil is satisfactory for pastures. The actual type of pasturage which it will be economical to stimulate on areas of this class is in some doubt. An average annual rainfall of 22 inches in Southern Victoria is on the border-line of the requirements of Perennial

Rye Grass. It seems quite clear that that species will not manage to maintain itself in these localities, unless the soil fertility is also maintained at a high level. In one or two of the low-slope paddocks Perennial Rye Grass seed has been scratched in without any previous attention to raising the fertility through the use of superphosphate and clovers. In general the results which have been achieved by this method have not been satisfactory. Exactly how far it would be necessary to raise the fertility before Perennial Rye Grass became permanently established, and the nature of the balance between the clovers and the rye grasses which would doubtless be necessary in order to ensure that degree of permanence are matters of speculation and considerable interest.

The main obstacle to intensive production on these low-slope areas is the impervious subsoil which hinders the downward percolation of water. Superficial drainage channels have been provided to some extent. Underground tile drains would be more effective, but too costly to be considered as a practical economic project. Even if this were not the case it would be necessary to consider their ultimate effects in the danger of causing the flooding of lands lower down in the same drainage system.

The wetness of these soils in the winter would make an agricultural system based on cultivation somewhat precarious, and it is probable that the most effective way of using the land is as pasturage, particularly if steps are taken to raise the productivity of the area by improving the types of plants which are grown. The extent to which this pasture improvement should be carried would depend upon the fertility problem which has already been stated above. It is, however, necessary to remember that improvement of pasturage will lead to a greater liability to stock diseases than is at present experienced. Disabilities of this type, however, can be overcome by the application of scientific knowledge in the management of the sheep. Some of the pastures are at present in large paddocks, some comprising 640 acres, and it is probable that subdivision which has been and is going on will lead to more effective utilization of the country. In this connexion, however, it must be remembered that water supplies are difficult during the summer months and usually entail the sinking of bores and the provision of tanks. The depth at which water can be struck below the basalt is very variable, and the costs have in many cases proved to be high.

The soils of the clay swamps are at least as difficult as those of the low slopes. Drainage is naturally the main problem, but even if this were satisfactorily solved the need for improving the physical features of the clays by increasing the amount of organic matter, or adding calcium compounds in the form of lime or gypsum, would still remain. The extent to which the relatively high salinity of these soils is a serious factor is at present unknown.

It is of some interest to note the following extract from *Western Victoria, its Geography, Geology, and Social Condition,* a narrative of an educational tour in 1857 by James Bonwick, who, when discussing a station some 4 or 5 miles away from the area which we have described, states: "The soil is not good for agriculture. Much of it was regarded as too poor for pastoral purposes; but the feed has greatly improved of late years. Exposure to cold winds, unbroken by hills or hedges, renders cultivation upon the plains anything but profitable. The same exposure and a want of drainage are formidable impediments to the breeding of sheep, though they fatten well upon the pasture. The farmer, again, could do little upon the Western Plains, for not only the reasons above mentioned, but for the difficulty of conveying produce in winter over the spewy ground; and the great distance often from wood and water. Stations have occasionally to send 30 or even 40 miles for firewood, and suffer much from want of running water. . . . The plains are best suited to sheep. In consequence of absence of timber, notwithstanding a hungry clay soil, the grass is so close, though short, and of so nutritious a character that sheep rapidly fatten." Nowadays the problem of water supply has been solved and firewood is grown in plantations on the stations. Drainage, though it has improved, is still a main problem. The carrying capacity of the country has been doubtless greatly increased in those places where top-dressing has been practised, but the land is still to a very large extent pastoral.

X. Notes on the Map, with Interpretation of Aerial Photograph.

It will be noticed that Types 4, 5, and 9 are the only types to be mapped simply as such; the other signs represent complexes. It was impossible on this scale to differentiate between the true stony-rise soils (Types 1 and 2) and the soils of the adjacent thistle zones (Type 3). These types have therefore been combined as "stony-rise complex." This procedure, although combining very different types of soil, has the merit of marking those areas which are too rocky for cultivation.

A different sign has been used for the pan-and-bank complex according as it occurs in swamps surrounded by slopes of soil Type 4 or those of Type 5, the banks being of light and heavy texture respectively in these two cases. Two further signs have been introduced to cover those areas which are transitional between the low-slope type and the respective pan-and-bank complex. These areas are easily picked out on the photograph by their stippled appearance. The occasional areas of soil type 6, uninterrupted by banks, are marked by the conventional sign for swamp. Types 7 and 8 are combined in the sign for the crabhole complex.

Two typical portions of the aerial photograph are reproduced on a large scale in Plate V. and the corresponding portions of the soil map are given in Figs. 11 and 12. On this scale one can separate the stony-rise complex into its parts so as to show the extent of the thistle zones (see legend on the large map). Types 2 and 3, however, are still mapped together. Except for a patch of Type 2 in the upper part of the lower photograph, the soils mapped under the sign of thistle-zone are in fact of Type 3.

The upper photograph shows a series of stony rises, in which the rocks stand out by reason of their light colour. The thistle-zone is shown by the dark rim around the rocks; ridges connecting rises also consist of this type. Where the sides are relatively steep, as here, the thistle zone forms only a narrow rim to the rises on their transition to the low slopes. The pan-and-bank complex is also well shown, especially in the upper right-hand corner, where the pans are covered with water which shows white on the pans and on the road. Below this and to the left, drains have been cut through the swampy country and most of the pans show as dark patches, where drainage, though still poor, is better than before. The lowest-lying part of this swamp is an unusually large expanse (13 acres) of soil Type 6. It is interesting to note that the outlet from this swamp has had to be cut through a stony rise.

Other swampy areas may be seen on this photograph. In the upper left-hand corner the transition from the pan-and-bank complex to the low-slope type takes place through the intermediate form referred to above. One or two isolated swamps may also be seen at the foot of one rise. Other interesting features in this photograph are the cattle in the swamp and elsewhere, e.g., at 1 inch to the right of the point of the arrow, and sheep tracks in the lower left corner.

The lower photograph is taken 3 miles north of the mountain where heavy soil (Type 5) is developed on the slopes. In such areas the crabhole complex is often developed on the swamps; it is easily picked out on the photograph on which the puffs appear as an assemblage of light spots. The lower-lying parts also include areas of heavy soil which is intermediate between the low-slope type and the pan-and-bank complex. The darker areas in the lower half of the photograph had been fenced and cultivated, sown to rye grass and surrounded by a shallow drain twelve years before the photograph was taken. The persistence of crabhole puffs in this enclosure is well shown. Some of this enclosed land was not cultivated because of its rocky nature; this part corresponds to two areas of thistle-zone just below the

Figs. 11 and 12.—Soil Maps corresponding to respective Photographs of Plate V. Signs have same meaning as on large map. Scale—Approx. 190 yards to 1 inch.

Portions of the Aerial Photograph.

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centre of the photograph. Below this again, and surrounded by two narrow cultivated strips, is another patch which was left uncultivated because the rapid drying out of the soil had left it too difficult to deal with during the season in which the rest of the work was done.

XI. Acknowledgments.

In making this study the writers have received assistance from many sources. Professor E. W. Skeats accompanied the party on two of its expeditions; his knowledge of the general geology of the area and of the Stony Rise country of the Western District in particular was of great value. Dr. R. T. Patton and Mr. H. C. Trumble helped with the identification of many of the plants. Mr. J. R. Freedman, B.Agr.Sc., was a member of the group during parts of 1933 and 1934, during which period he gave valuable assistance both in the field and laboratory. The labour of the work was reduced immeasurably by the kindness and courtesy of the Royal Australian Air Force in taking the aerial photographs and in making the mosaics. The Trustees of the Science and Industry Endowment Fund of the Commonwealth assisted by making grants to Miss Nicholls.

Finally the whole project would have been impracticable without the unfailing hospitality and interest of our hosts, Mr. and Mrs. R. A. Ramsay of "Mooleric," and Mr. and Mrs. Urquhart Ramsay of "Turkeith."

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XIII. Names of Soil Types.

After consultation with Professor J. A. Prescott, the authors have assigned the following names to certain of the soil types here described:—

1. Corangamite stony loam.
3. Mooleric clay.
4. Grenville loam.
5. Grenville clay.
6. Grenville clay (swampy phase).
7 and 8. Turkeith clay.
9. Mount Gellibrand clay loam.

Explanation of Plates.

PLATE VI.

Fig. 1. Trench under puff in crabhole formation. Note crumbly soil and patches of calcium carbonate near surface. The greyish-yellow calcareous horizon begins just above metallic part of spade.

Fig. 2. Trench under depression two yards from Fig. 1. Horizontal cut marks the beginning of the greyish-yellow calcareous horizon, which is at the same level as the corresponding horizon in Fig. 1.

Fig. 3. Stony rise, with thistle zone seen on skyline; in the foreground is a swampy patch with tussocks of *Poa caespitosa*.

Fig. 4. Low slope, with incipient pan-and-bank formation.

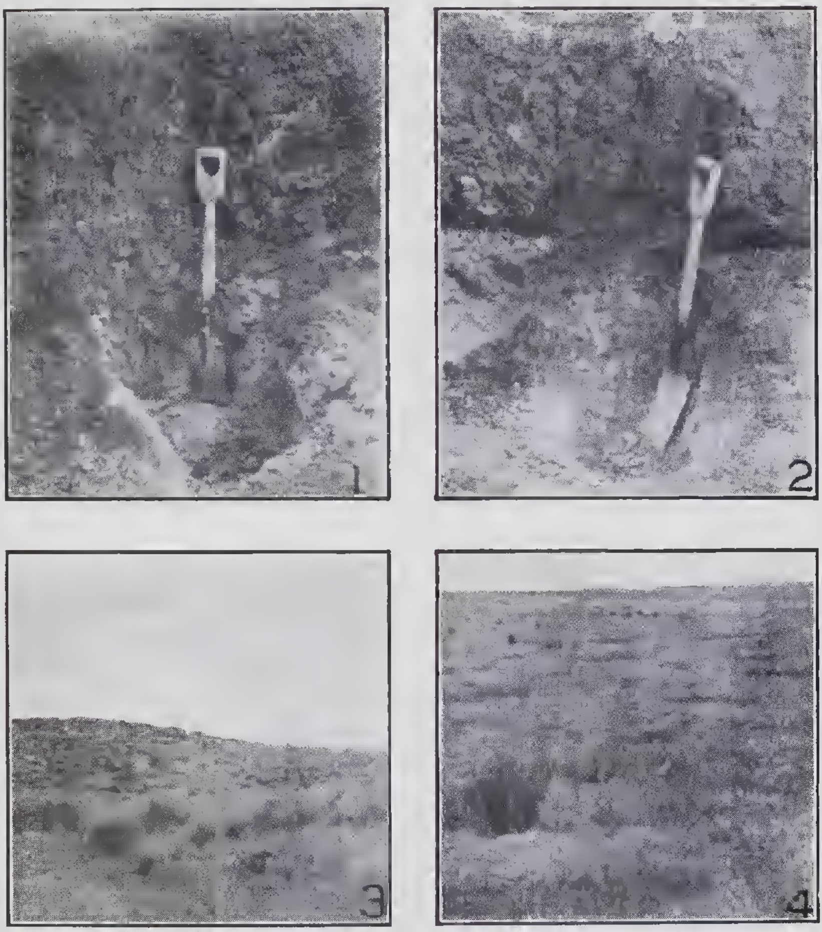
PLATE VII.

Fig. 1. Vegetation on a stony rise between boulders.

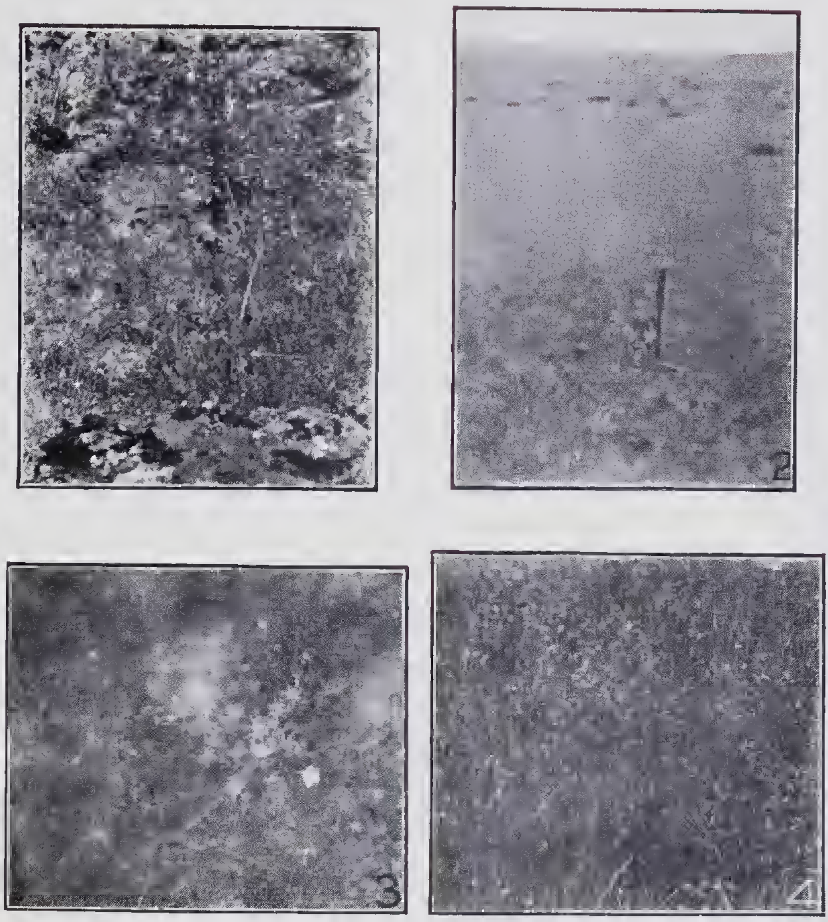
Fig. 2. Vegetation on large drained clay pan (Type 6) in early stages of colonisation.

Fig. 3. Vegetation on a rather poor low slope. *Danthonia semiannularis, Eryngium rostratum, Convolvulus erubescens,* and *Cuscuta epithymum* with many open spaces.

Fig. 4. Vegetation of an undrained pan. *Danthonia semiannularis, Amphibromus nervosus,* and *Heliocharis acuta.*



Features of Soil and Vegetation.



Typical Vegetation of the Area.